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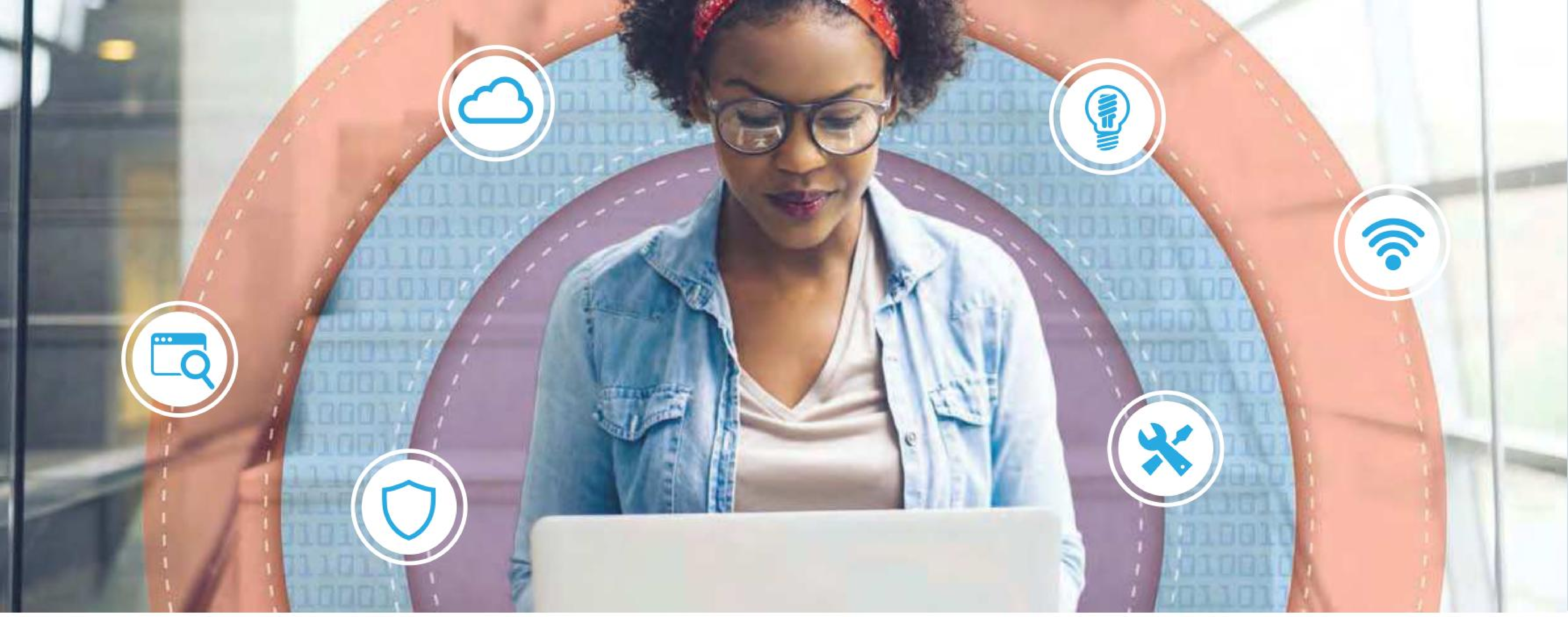

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ISSN 2632 573X

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Made in the UK.

Written in Britain, Australia, the US and Ireland.

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The November 2021 issue of *Practical Electronics* will be published on Thursday, 7 October 2021 – see page 72.

WIRELESS FOR THE WARRIOR

by **LOUIS MEULSTEE**

THE DEFINITIVE TECHNICAL HISTORY OF RADIO COMMUNICATION EQUIPMENT IN THE BRITISH ARMY

The *Wireless for the Warrior* books are a source of reference for the history and development of radio communication equipment used by the British Army from the very early days of wireless up to the 1960s.

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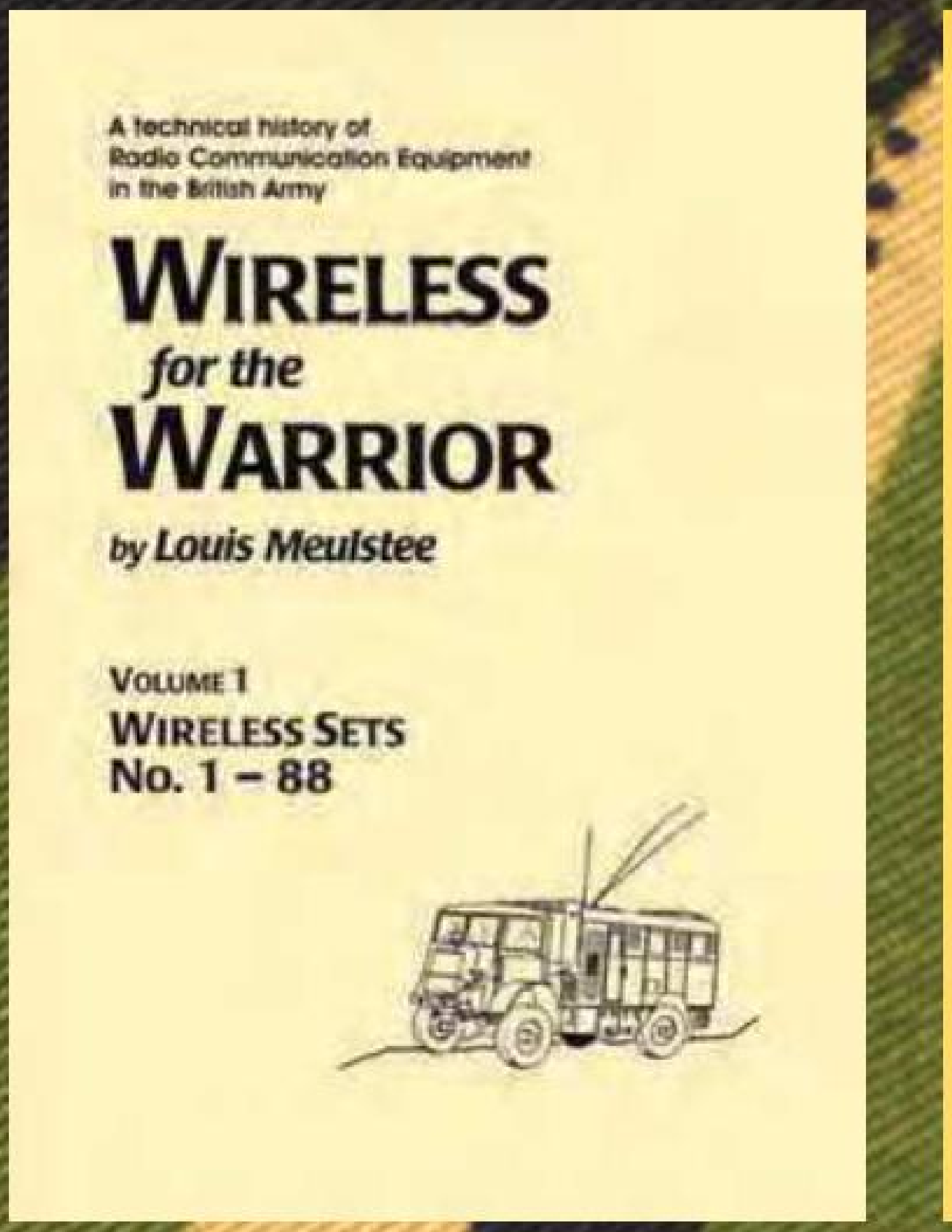
Volume 3 covers army receivers from 1932 to the late 1960s. The book not only describes receivers specifically designed for the British Army, but also the Royal Navy and RAF. Also covered: special receivers, direction finding receivers, Canadian and Australian Army receivers, commercial receivers adopted by the Army, and Army Welfare broadcast receivers.

Volume 4 covers clandestine, agent or 'spy' radio equipment, sets which were used by special forces, partisans, resistance, 'stay behind' organisations, Australian Coast Watchers and the diplomatic service. Plus, selected associated power sources, RDF and intercept receivers, bugs and radar beacons.



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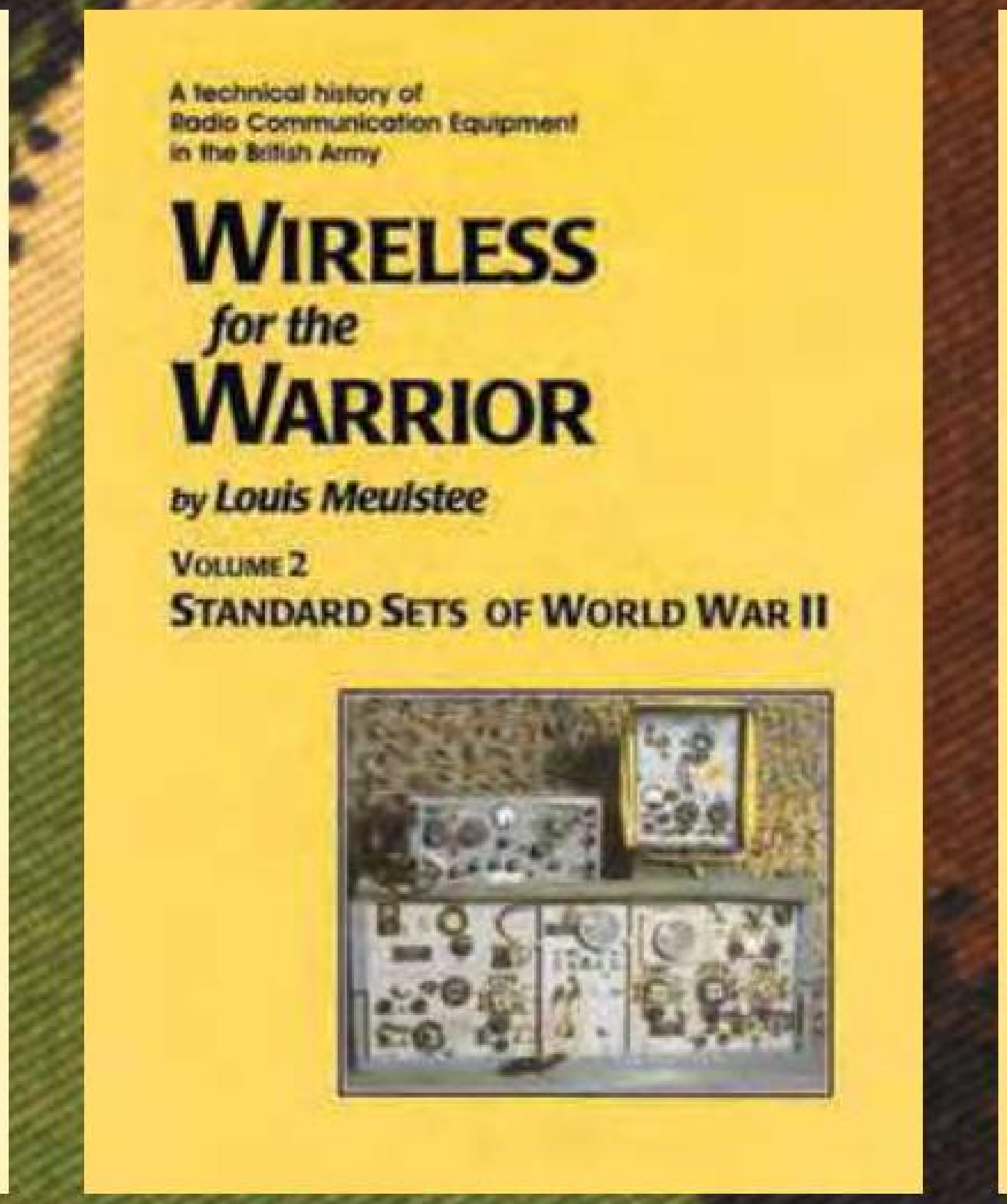

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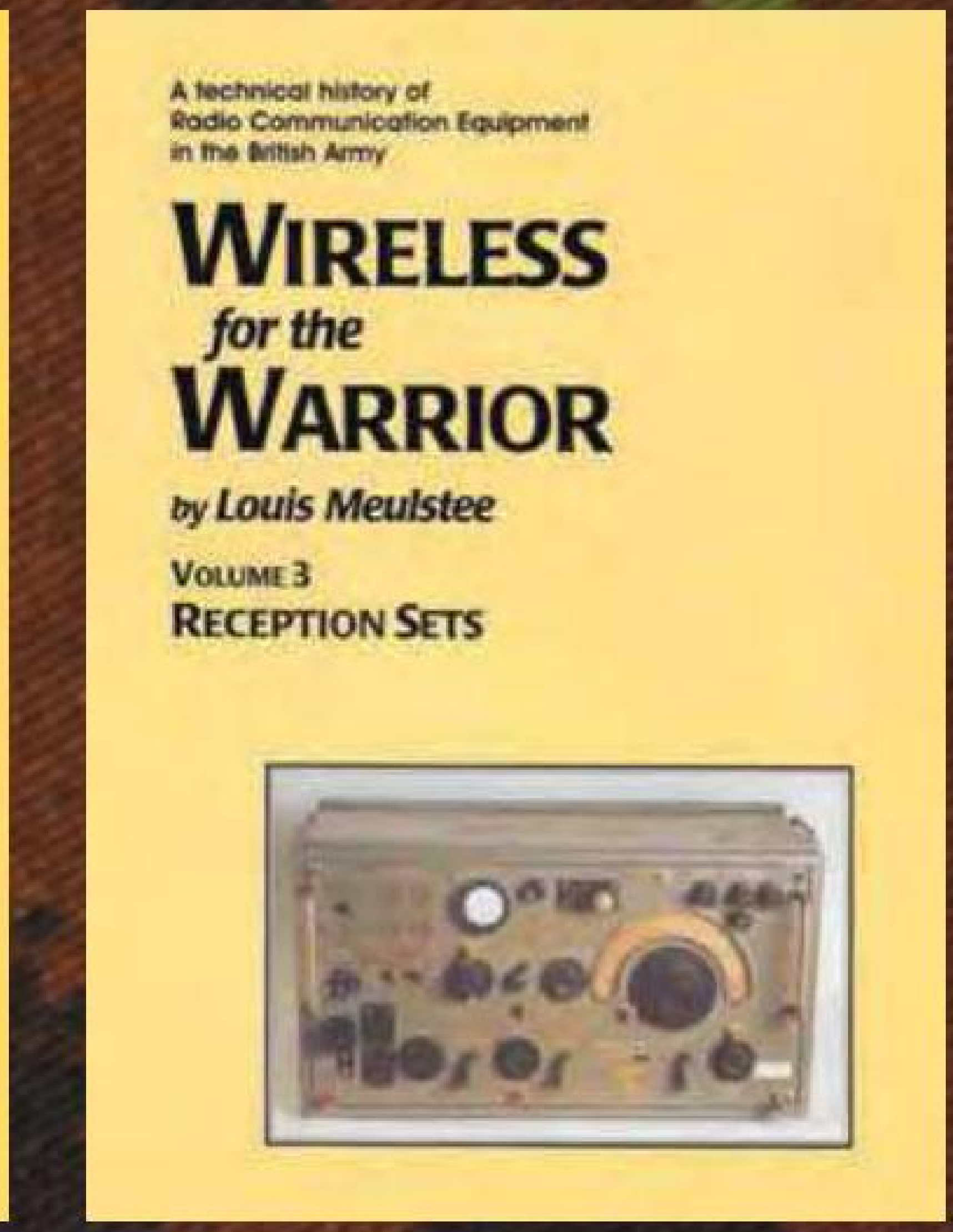

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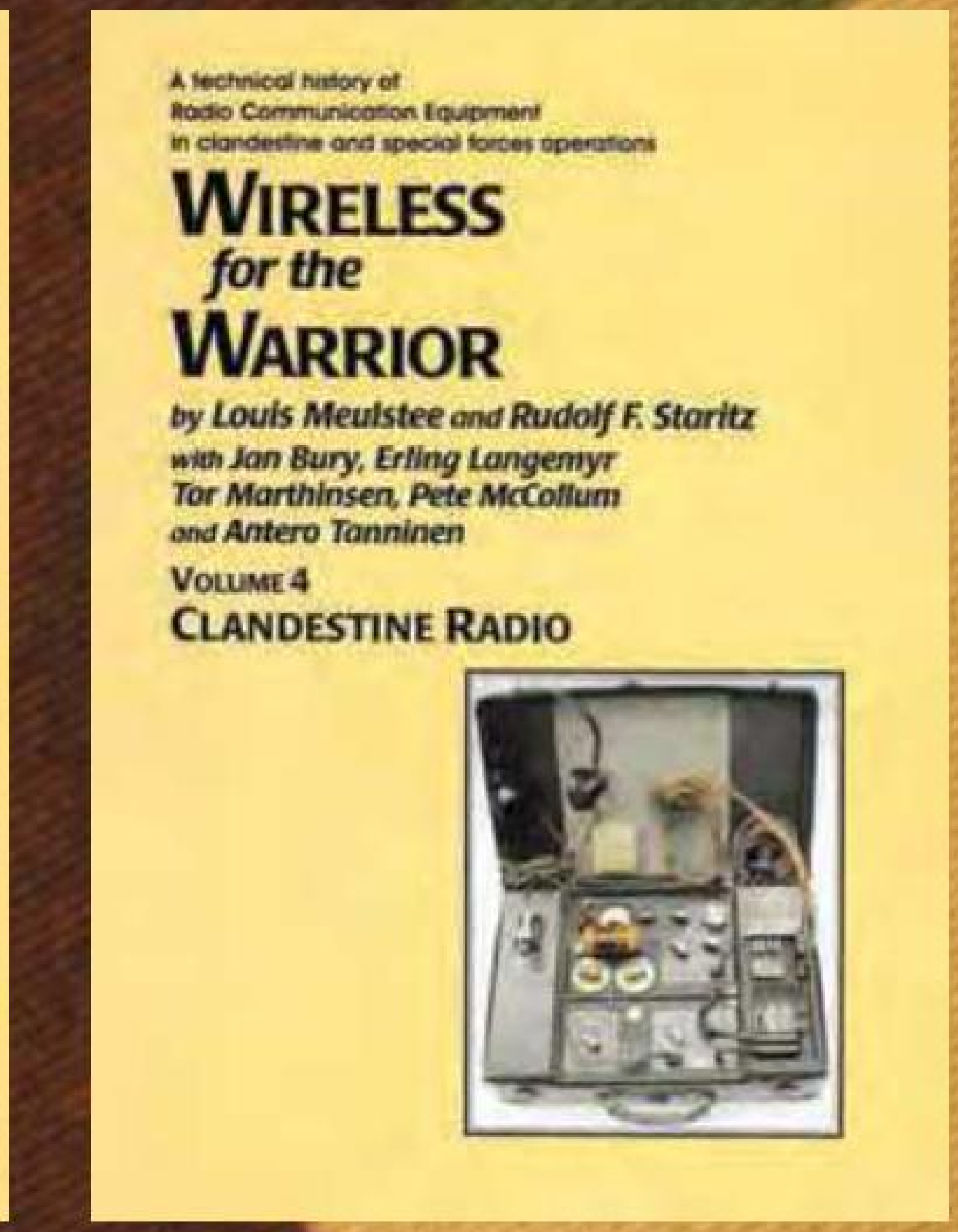

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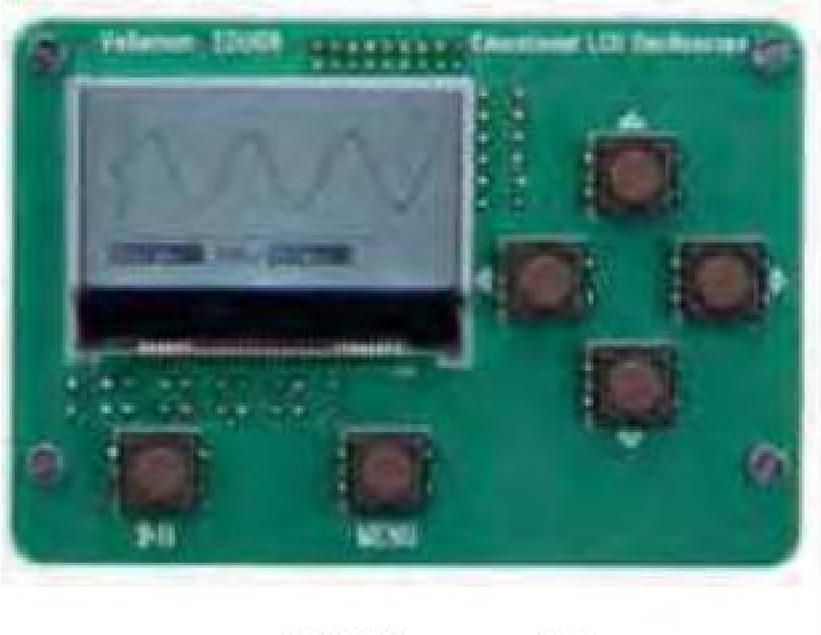

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October 2021
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Questions about articles or projects should be sent to the editor by email: pe@electronpublishing.com

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All reasonable precautions are taken to ensure that the advice and data given to readers is reliable. We cannot, however, guarantee it and we cannot accept legal responsibility for it.

A number of projects and circuits published in *Practical Electronics* employ voltages that can be lethal. You should not build, test, modify or renovate any item of mains-powered equipment unless you fully understand the safety aspects involved and you use an RCD (GFCI) adaptor.

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We do not supply electronic components or kits for building the projects featured, these can be supplied by advertisers. We advise readers to check that all parts are still available before commencing any project in a back-dated issue.

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More Cricket

We introduced the clever little IoT Cricket back in the June issue, and we know you liked it from the large number of devices purchased with the *PE* discount code. Well, the good news is there is more Cricket this month as we learn how to integrate it with Raspberry Pi via the 'codefree' programming environment Node-RED. This is the next stage in a series that will explain how to build small-scale, low-power, Wi-Fi-based home automation systems that can collect, process and act on sensor-acquired data. Cricket is definitely 'one to watch' – it's inexpensive, easy to use and can happily run for months on just one or two AAA batteries. (Plus, if you decide to buy a Cricket then do make sure you take advantage of the *new* special offer from **OKdo.com** at the end of the article!)

Maximite 2 (Gen 2)

Another welcome return is the latest version of the *Maximite*, an inexpensive, compact, single-board retro (1980s-style) home computer programmed in MMBasic. Many of you built the first version a couple of years ago, and now it's back with a much more powerful processor, more memory and a whole host of other improved features. If you liked the first one, you'll love this upgraded model!

Further projects

But wait, there's more! On top of *Maximite* and Cricket we're adding Wi-Fi connectivity to LCD Touchscreen *Micromite BackPacks*; detailing the construction of our *High-power Ultrasonic Cleaner*; and we have the second part of our state-of-the-art *USB SuperCodec*. Time to get the soldering iron out!

Radioactive Diamond Batteries

Finally, the above is my favourite headline of the month. In fact, it came from a 2020 article, but I only recently stumbled across it in *The Wire* magazine (**https://bit.ly/pe-oct21-dia**) looking for something completely unrelated – that's the fun of clicking on hyperlinks! These devices sound like something out of *Star Trek* or the *Marvell Universe* – however, not only do 'radioactive diamond batteries' really exist, but they also offer some genuinely unique and useful properties. Just for starters they are very long lived and could eat up radioactive waste produced in nuclear power stations. It's a fascinating piece of research, and in case you hit a paywall at *The Wire*, you can read about these revolutionary mini power plants for free at the Bristol University website: **https://bit.ly/pe-oct21-c14**

Keep well everyone

Matt Pulzer
Publisher

The **Fox** Report

Barry Fox's technology column

Pingdemic blues

In the UK (and doubtless elsewhere) the virus pandemic was overtaken by a 'pingdemic', with rafts of keyworkers forced to self-isolate because they had been 'pinged' by the NHS Covid-19 *Track and Trace* smartphone App. The App works with Bluetooth, registering and then messaging anyone who has come close to someone who has later fallen sick. When the App was criticised for over-enthusiastic pinging, and people started deleting it from their phones, the powers that be talked vaguely about tweaking the App's sensitivity.

A simple DIY test shows how the App design was fatally flawed. Take a trip on public transport, a train or a tube/subway, and go to the Bluetooth settings on your smartphone. This will show all Bluetooth devices available for pairing, because they are within Bluetooth range – and thus 'visible' to the Covid App. Now watch how the list of detected devices changes as passengers join and leave the train. Some will be way down the carriage far beyond the 2-metre medically safe social distancing limit.

Social vs Bluetooth distancing

Bluetooth has a range of around 10 metres or over 30 feet, so the App is detecting people at five or more times the 2-metre safe distance.

The official NHS explanation of how the App works reads: 'Close contact' is based on an algorithm, but generally means you've been within 2 metres of someone for 15 minutes or more.

Often, a tube or rail journey will be for over 15 minutes. Phone users have no options for controlling Bluetooth transmission strength or reception sensitivity. Talking about tweaking the algorithm to control electronic sensitivity is like talking about Harry Potter magic.

I asked the NHS Press Office, 'what is to prevent smartphones detecting devices at the Covid-safe distance of 10 metres or more, for 15 minutes or more, and "pinging" the owners with a false warning of dangerously close contact?' My questions were simply ignored. I am not surprised.

Baroness Dido Harding was the executive chair of the £35bn+ coronavirus Test and Trace programme. She was previously head of telecoms giant Talk Talk. It was on her watch that the network was hacked by teenagers, resulting in customers having their personal details stolen.

I know because I was at the time (2015) a Talk Talk Customer and received the letter which TalkTalk sent to everyone who was compromised. It's never been clear just what data was stolen and how much of it was encrypted and how much unencrypted. I'll never how much of the cyber-aggro I now suffer is thanks to Talk Talk and Baroness Harding.

If Baroness Harding was judged the best person for the App job, who else applied? What I do know for sure is that when we recently learned that Baroness Harding was applying for the job of running the whole NHS, I signed the petition to stop her.

Slow and steady wins the day…

A reader recently contacted me:

'I escorted an elderly friend to buy a mobile phone at an EE shop. The buttons became illegible in a very short time, so we went back to complain. The shop manager insisted we were outside their 28-day money back guarantee period, and we should take it up with the manufacturer. He refused to acknowledge our rights under consumer legislation.

'I then wrote to EE head office, complaining that their representative was breaking the law, but they refused to discuss the matter with me because I was not the 'account holder' (what does that have to do with it?).

'Then I tried to take the matter up with Trading Standards, who refused to accept a complaint from an individual consumer and directed me to Citizens Advice. Citizens Advice consisted of merely referring me to leaflets about consumer rights legislation. Round and round the mulberry bush.

'It seems that no matter what one's legal rights might be, there is no means to have them enforced unless it is

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worth the expense of private prosecution. Also, organisations are misusing data protection laws to avoid asking legitimate questions.'

I replied, 'The trick to getting satisfaction on a genuine (not vexatious) complaint is to find the right button to press, often the relevant ombudsman. At worst, you have the satisfaction of knowing that the target of the complaint has had to do a lot of work defending themselves.

'Unfortunately, Covid has provided a wonderful opportunity for some people and organisations not to do their job properly. This includes bodies and people who are being paid to handle complaints.

'My way of working – learned the hard way – is to bide time and make a clear detailed note of anything I may want to come back to. Don't get diverted by phone calls or shopfloor conversations which can be denied.

'Once the detailed note is written it can just sit waiting until the time is right. The target of the complaint will then have to dig into old files and memories to argue in defence. Again, you will at least have this satisfaction.'

When is live music real?

We hear a lot about pop singers secretly benefitting from pitch correction, to make recordings sound much better than the real thing. But of course, we never get to compare the real thing with the processed song.

Recently, a musician friend found this pair of gems on the Internet. Apart from the entertainment value, like a movie so bad it is good, the before and after comparison makes a very useful technology demonstration. See: **https://youtu.be/5sN7kgEw954** and **https://youtu.be/E6ERPeGkBt8**

An amusing BBC report (**https://bbc.in/2VUDWxX**) noted that one YouTube commenter wrote: 'She is actually hitting all the notes... only of other songs. And at random.'

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Data Discman

Sprachen der Welt

The Data Discman from Sony – a solution looking for a problem that never appeared.

When Sony announced that, 'Tomorrow's mobile library' was on sale in Japan in July 1990, it was an immediate hit with the gadget-hungry Japanese.

Sony's Data Discman (DD) was a portable CD player with an LCD screen and small qwerty keyboard. It played 8cm electronic books with 200MB capacity. There was a choice of 35 reference textbooks and foreign language dictionaries.

DD hit the US and mainland Europe the next year, with 85 titles including such 'un-missables' as an information disc on US Presidents. By 1992, 100,000 players had been sold – *but*, only 200,000 discs.

Unfortunately, there were problems. Discman ROMs discs were incompatible with conventional PC ROM drives. Compatibility with Philips' CD-interactive players was promised but never happened. The DD discs stored only raw data, so the player had search software built into its on-board electronics. To prevent users from downloading this raw data, the player had no socket for connection to a PC.

The UK got the chance to buy DD players in April 1992 for £350, with a Dictionary of the Living World priced at £60 and Harrap's Multilingual Dictionary costing £40. However, the small monochrome LCD screen was so hard on the eyes that Sony always demonstrated it connected to a TV monitor.

'I tried reading the works of Mark Twain,' said one American user, 'but very soon gave up.' Sony countered that DD was ideal for finding out how many times Sherlock Holmes said 'elementary' or how to say 'gasket' in German if you break down on the Autobahn. A deal with BT to put telephone directories on DD discs fell through.

Divided by incompatibility, and trounced by PC ROMs, DD flopped.

A strange epilogue to this story is that in 1997 a batch of brand-new, boxed Data Discmen appeared in the window of a Tottenham Court Road shop in central London. They were labelled as if the format were new and the latest thing in portable computing!

More technology stories and images at: **https://tekkiepix.com/stories**

Practical Electronics is delighted to be able to help promote Barry Fox's project to preserve the visual history of pre-Internet electronics.

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Hacker heritage

Techno Talk

Mark Nelson

Could a model railway club have kickstarted today's maker movement by inventing computer hacking 60 years ago? Some people reckon it did, as you will read in this article. If that sounds like an outlandish claim then prepare to be amazed, because truth is often stranger than fiction.

Is there a natural affinity between hobby electronics and model railways? Probably – this magazine has featured several projects that combine them. And if you visit **https://merg.org.uk** you'll discover MERG (Model Electronic Railway Group), which is an international, UK-based society promoting interest in the application of electronics and computers to all aspects of railway modelling. Their acclaimed textbook *Electronics for Model Railways* is available for free download at: **https://merg.org.uk/content/ebook**

US origins

Interest in melding electronics with model railway operation goes a long way back – arguably to 1946, when students at MIT (Massachusetts Institute of Technology in the US) began work on a vast HO-scale layout that specialised in the automated operation of model trains. As the article at **https://bit.ly/pe-oct21-tmrc** explains in greater detail, the Tech Model Railroad Club (TMRC) became a wellspring of hacker culture and begat the first hacking group in North America. By the mid-1950s, the club had installed a semi-automatic control system based on telephone relays that could run a train over the entire set of tracks, in both directions without manual intervention: throwing switches and powering tracks ahead of the train. A decade later, the telephone manufacturer Western Electric donated to the club a crossbar telephone exchange switch under its college gift scheme. As well as controlling train operations, the expanded setup now featured a digital clock display and an internal telephone system with external dialling-out lines, all built from telephone stepping switches and relays.

Onwards and upwards

While many club members were content with building rolling stock and scheduling timetables, the truly 'techie' experts felt driven towards more challenging projects. These students shared a passion to find out how things worked and then to master them. Many who had been 'exploring' the phone switching network were now being drawn into computer programming, inventing novel techniques, ingenious shortcuts and a language of their own. One of the words they coined was 'hacker' and according to *The History of Hacking* (**https://bit.ly/pe-oct21-hack**), this term 'hacking' originated at MIT in the 1960s.

Marvin Minsky, the director of the MIT Artificial Intelligence Lab, was sympathetic to the hackers' desire to experiment, and was so impressed by their accomplishments that he allowed them to have access to the machines in his lab. Erik Brunvand, author of *A Little Bit of Hacker History* (**https://bit.ly/pe-oct21-mit**), describes the 1960s as the 'golden age of the computer hacker'. In his words, 'the machines were large, slow, cumbersome to use, and it took an extraordinary effort to make them do even the simplest computation. The legendary feats of the early hackers are made even more amazing when you consider the primitive nature of the machines they were using and the tools they had at their disposal.'

Good guys gone bad?

Few things in life are constant, and inevitably hacker activity evolved over time. A turning point took place in 1975 with the formation of the Homebrew Computer Club in Menlo Park, California. This group of computer hobbyists included folk like Apple Computer founders Steve Jobs and Steve Wozniak, and they played an influential role in the development of the microcomputer revolution and helped stimulate the rise of Silicon Valley. In those days, computer hackers were seen as computer experts who used their knowledge to achieve a goal or overcome an obstacle, within a computerised system by non-standard means.

Gradually, however, the term took on a negative connotation and computer hackers are now more commonly perceived as unauthorised users who break into computer systems to steal, ransom, change or destroy information, often by installing dangerous malware without the knowledge or consent of their users.

Of course, enlightened folk recognise that not all hacking is malevolent and it's only the so-called 'black-hat' hackers who operate with malicious intent. 'White-hat' hackers are the good guys who identify system vulnerabilities in order to fix them. Occupying the middle ground are 'grey-hat' hackers (typically political activists) who justify their actions on ethical grounds.

Does true hacker culture still exist?

Arguably yes, but under a different name. In the 1980s, hackers wanted machines that they could modify and program themselves. Since then, users' horizons have evolved and expanded, but the underlying desire to create high-tech machines at affordable prices using homebrew techniques is a constant theme. Only the name has been given a makeover and we now call it 'maker culture'.

It's hard to better the definition offered by Wikipedia, namely that maker culture is a contemporary subculture representing a technology-based extension of do it yourself (DIY) activity that intersects with hardware-oriented parts of hacker culture and revels in the creation of new devices as well as tinkering with existing ones. Typical interests enjoyed by the maker culture include engineering-oriented pursuits such as electronics, robotics, 3-D printing and the use of computer numeric control tools.

Maker culture is now well supported by magazines and websites. Its image is positive, with many activities run on a collaborative, not-for-profit basis. There are public expositions called 'maker faires' (or something similar name), while all manner of maker spaces such as 'fablabs' (fabrication laboratories; ie, small-scale workshops) are making digital manufacturing facilities accessible to business start-ups, groups and private individuals. Programmable microcontrollers and single-board computers such as the Arduino and Raspberry Pi, combined with plentiful open-source software are lowering the entry cost of hardware development. Online funding platforms such as Kickstarter and Patreon are examples of financial support to the maker community. 60 years on, it's a great time to revive and maintain the true hacker spirit!

Exclusive offer

Win a Microchip PIC32 WFI32E Curiosity Board

Practical Electronics is offering its readers the chance to win a Microchip PIC32 WFI32E Curiosity Board (EV12F11A) – and even if you don't win, receive a 20%-off voucher, plus free shipping for one of these products.

The PIC32 WFI32E Curiosity Board is an easy-to-use evaluation tool to determine the performance of the WFI32E01PC Wi-Fi MCU module, which contains the PIC32MZW1 series Wi-Fi SoC.

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There are assorted types of on-board connecting headers for users to build up their applications by connecting to add-on boards, such as Microchip's XPRO boards. Users can also expand functionality through MikroElectronika mikroBUS Click adapter boards.

The PIC32 WFI32E Curiosity Board has the PICkit On-board (PKOB) debugger based on a PIC24FJ256GB106 USB microcontroller. Additionally, it supports external debuggers, such as MPLAB REAL ICE and MPLAB ICD 3 by connecting to the ICSPTM header.

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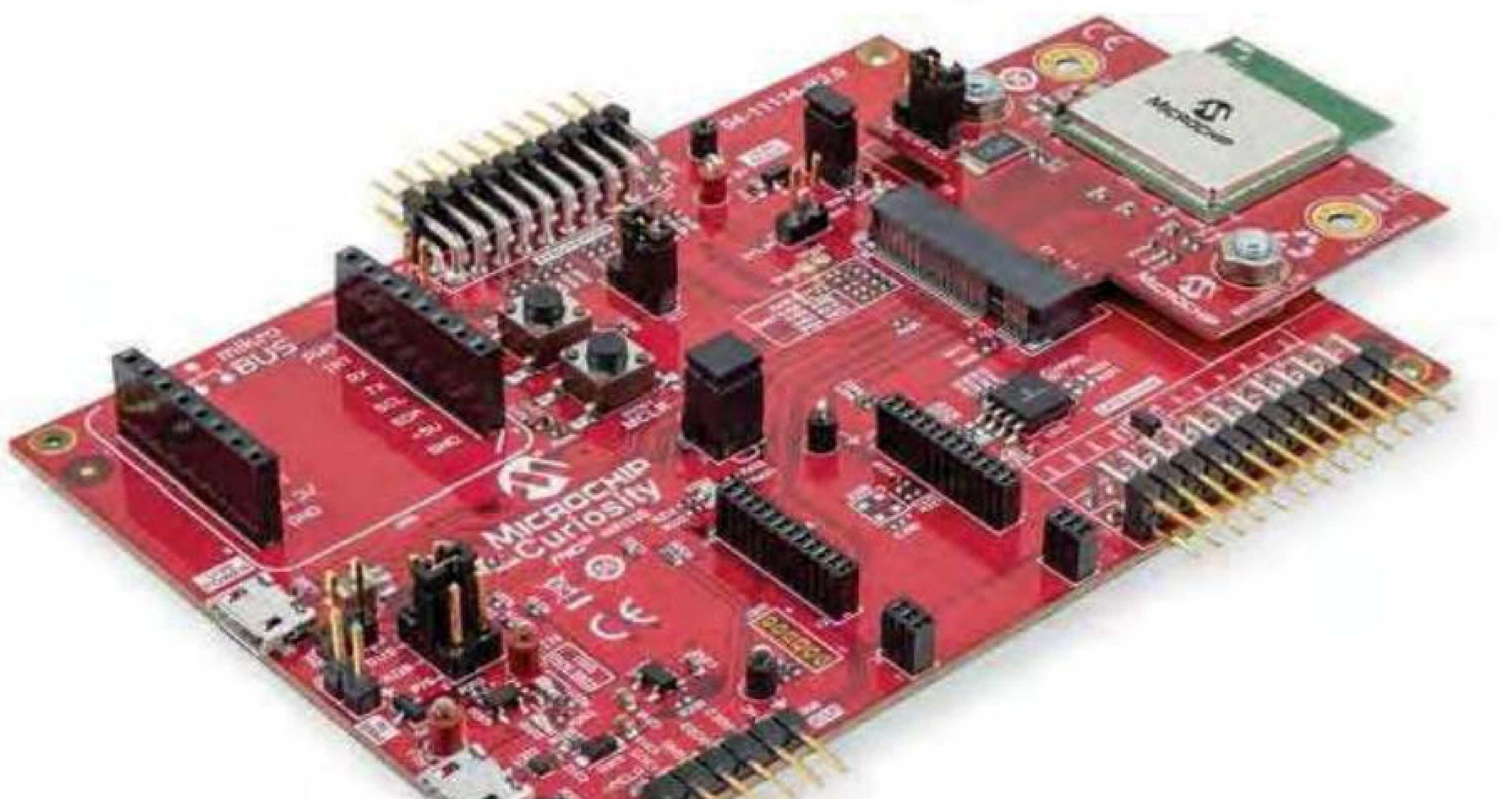

Microchip PIC32 WFI32E Curiosity Board

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The closing date for this offer is 30 September 2021.

June 2021 winner

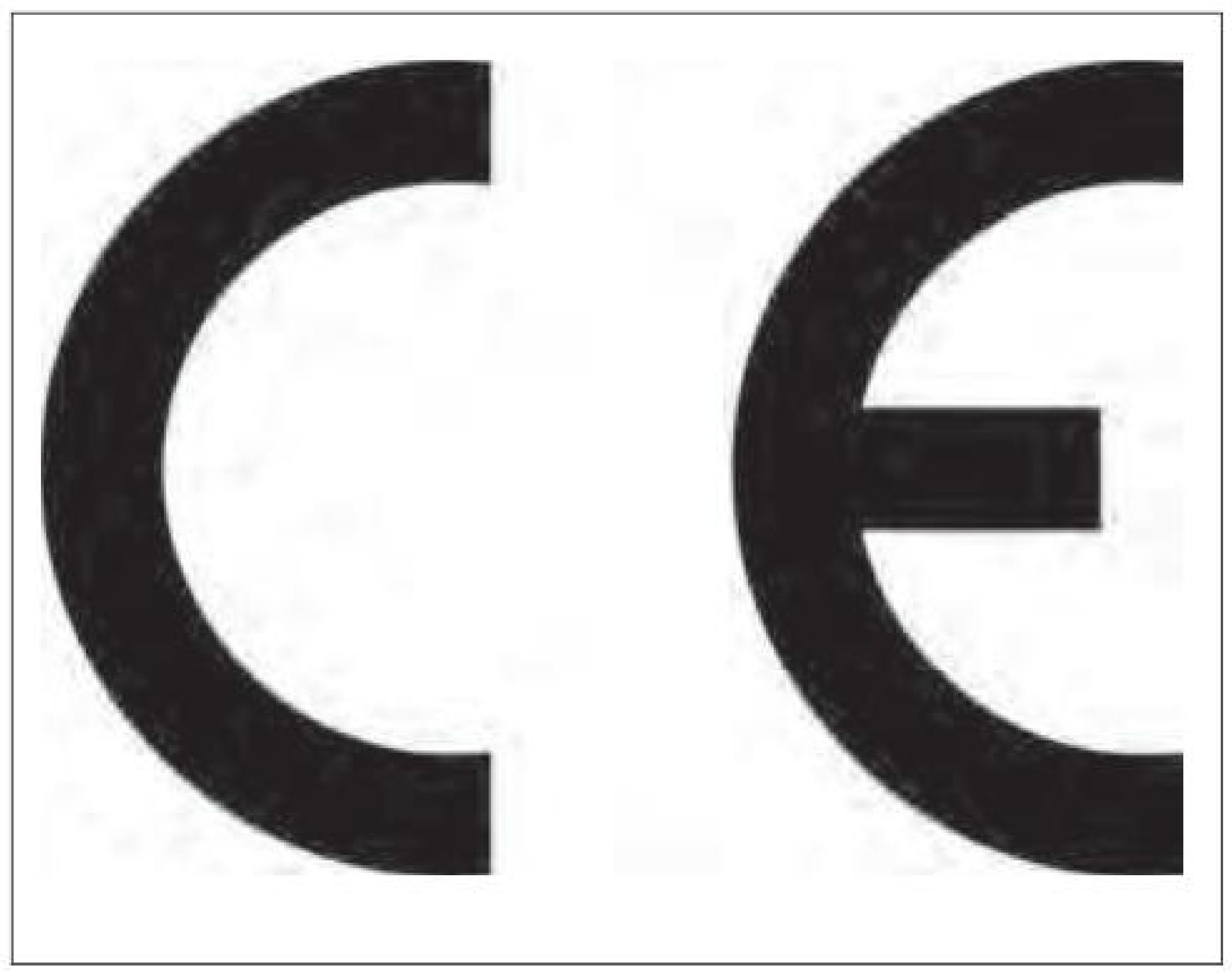
Mike Ward

He won a Microchip MCP19114 Flyback Standalone Evaluation Board

Net Work

Alan Winstanley

This month, *Net Work* warns readers to beware of fake, false or misleading CE markings, and looks to the future of metering and power.



The genuine CE mark, distinguished by the character spacing and circular font.

While surfing around a Facebook group dedicated to electrical equipment, I came across an interesting thread discussing 'CE' marking on electronic gear and components. What caught my eye was the seemingly serious suggestion that a logo similar to the European 'CE' mark was used by some Chinese manufacturers to mean 'China Export' rather than *Conformité Européenne*.

This particularly piqued the writer who, half his career ago, was involved with ISO9000 quality management, grappling with countless British Standards, Euronorms (EN regulations) and all manner of quality assurance regulations. The European Union is a 'single market', so in the interests of 'harmonisation,' EU regulations are supposedly transposed into the member states' national laws and this includes product testing, safety and labelling. Consumers could therefore be confident that uniform quality standards were consistently adopted across the Union and, regardless of which EU country the item was being marketed, the product would be 'compliant' with all prevailing laws. For anyone who's interested, the official (English) website of the European Union – **https://bit.ly/pe-oct21-eu** – highlights the work of its 55 departments: bedtime reading it is not!

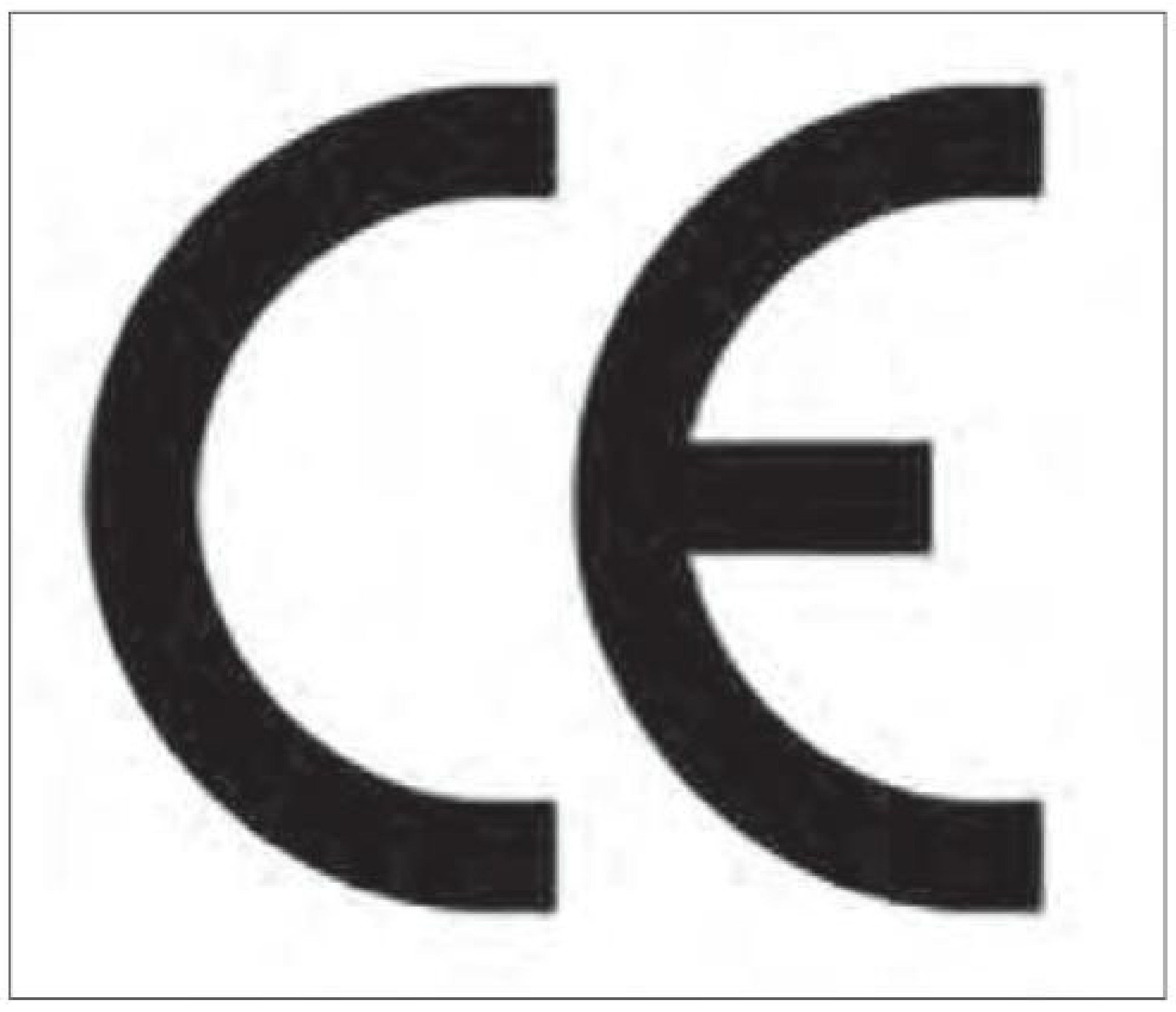
Here in Europe, everyone is familiar with the authentic CE mark that appears on all manner of goods. It indicates that the product complies with appropriate legislation. Most ordinary consumers view the CE approval mark as a symbol denoting product safety. For instance, a toy that complies with EN71 (the Toy Euronorm) won't have any sharp edges, finger traps or easily detached small parts, and it will be both non-flammable and non-toxic. Electronic equipment sporting a CE mark will comply with the European Electromagnetic (EMC) Directive, Low Voltage Directive and probably lots more besides, while items of PPE (personal protective equipment, such as facemasks or goggles) will have a CE mark signifying rigorous compliance with some very stringent laws. (For just masks, one can only marvel at 48 pages of EU PPE legislation at: **https://tinyurl.com/2pt2trnd**). Many EU laws are 'sold' in deceptively simple-sounding terms, but the devil is usually buried in the technical detail.

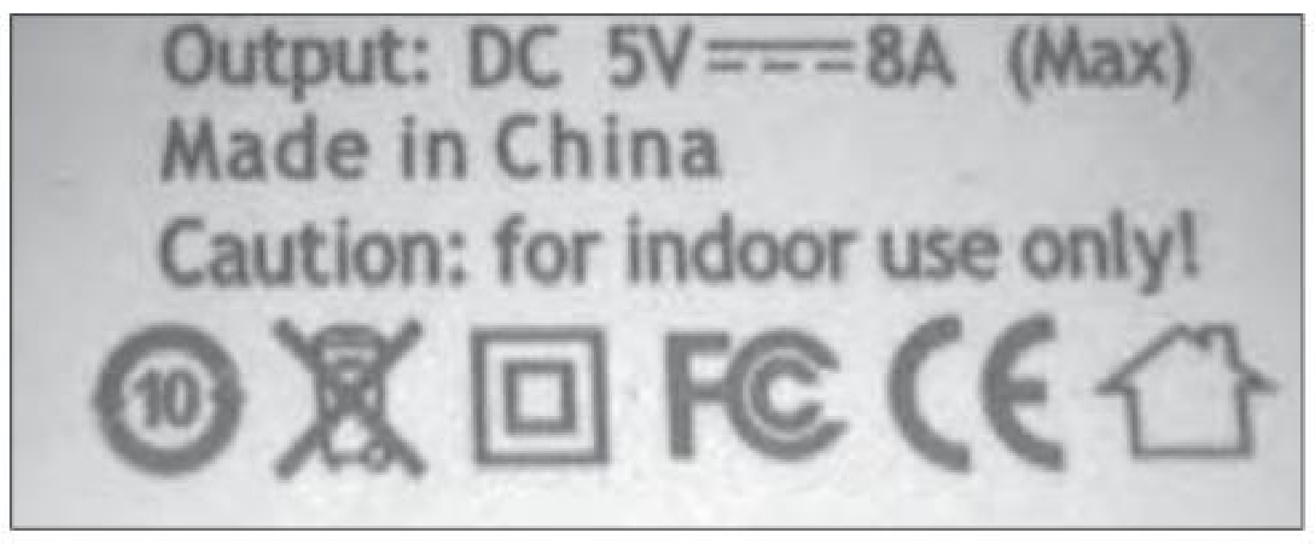
The genuine article

An eagle-eyed user will soon spot a genuine CE mark: the letters are derived from two sets of intersecting concentric circles, and when viewed on a 20×20 grid the semi-circular symbols are actually 20-units high but 11-units wide (ie, one unit greater than being semi-circular). The strokes are three-units thick. Critical are the separation between the two letters (see **https://bit.ly/pe-oct21-euce**) and the perfectly circular style of the font.

In addition to a product's CE marking, a 'technical dossier' about it will be held by the manufacturer which contains fully documented evidence of product testing and approvals. Local authorities may demand to see it in the future. A so-called 'EU Declaration of Conformity' is also signed by the manufacturer as proof of product compliance; they're a familiar sight, and are often included with the product's instructions.

Unfortunately, worthless variations of the authentic CE mark are sometimes found on a range of disreputable imported goods. The reason is likely to be very simple: the goods are fake, non-compliant and haven't been tested, but given a quick glance a bogus CE logo can pass as the real thing. The CE letters may be bunched up closely together or otherwise misshaped, but they are *not* the real deal. To put our cards on the table: it's totally inconceivable that, of all the designs, logos and typefaces that could be used by foreign makers, a supposed 'China Export' symbol should be dreamt up that coincides so very closely with the genuine CE mark. As an example, the author snapped a lookalike CE mark on a USB charger: see above and note how the CE letters butt up to each other.





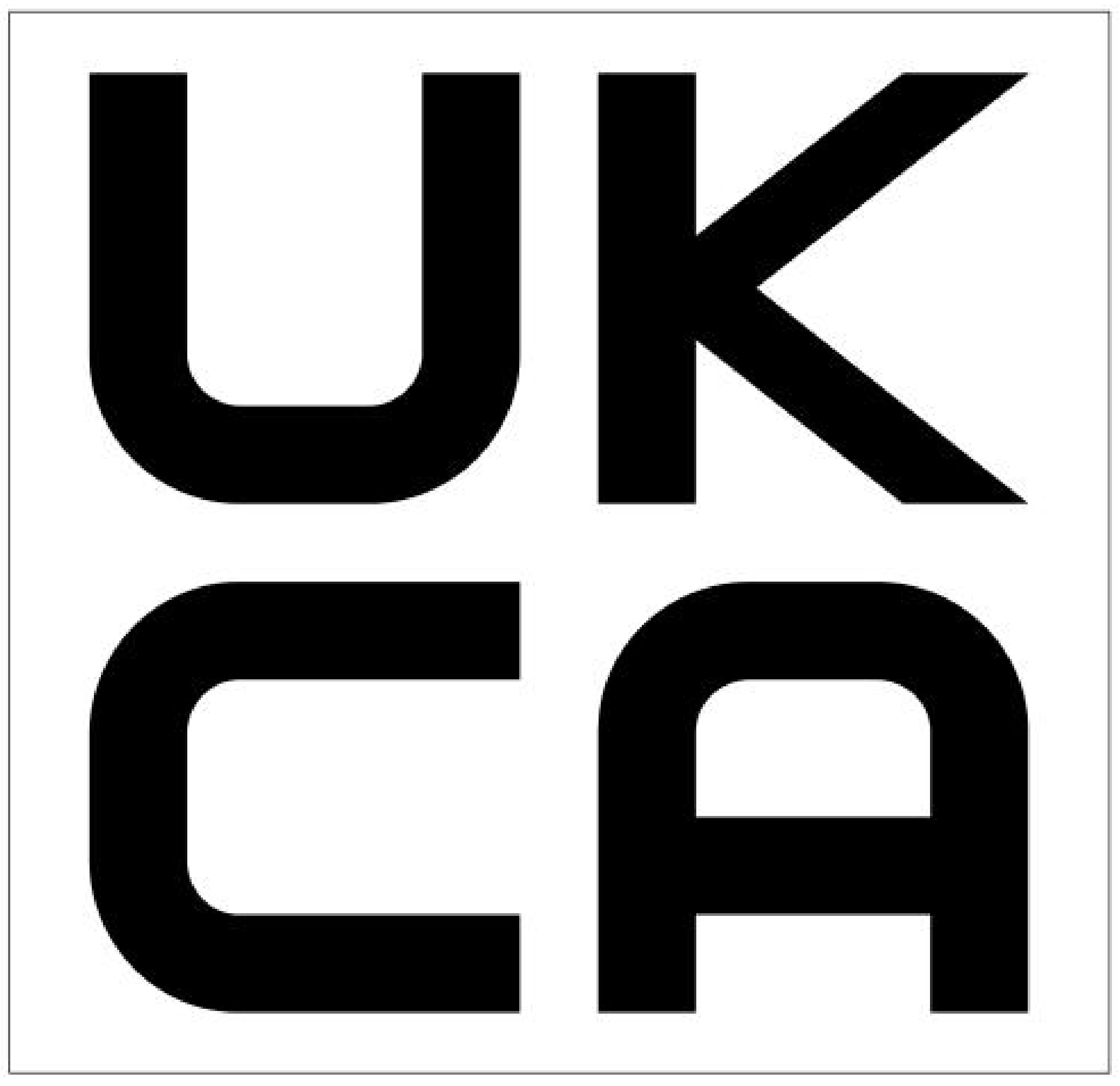
Output: DC 5V⎓8A (Max)
Made in China
Caution: for indoor use only!

A non-compliant CE mark found on a USB charger – compare the character spacing.

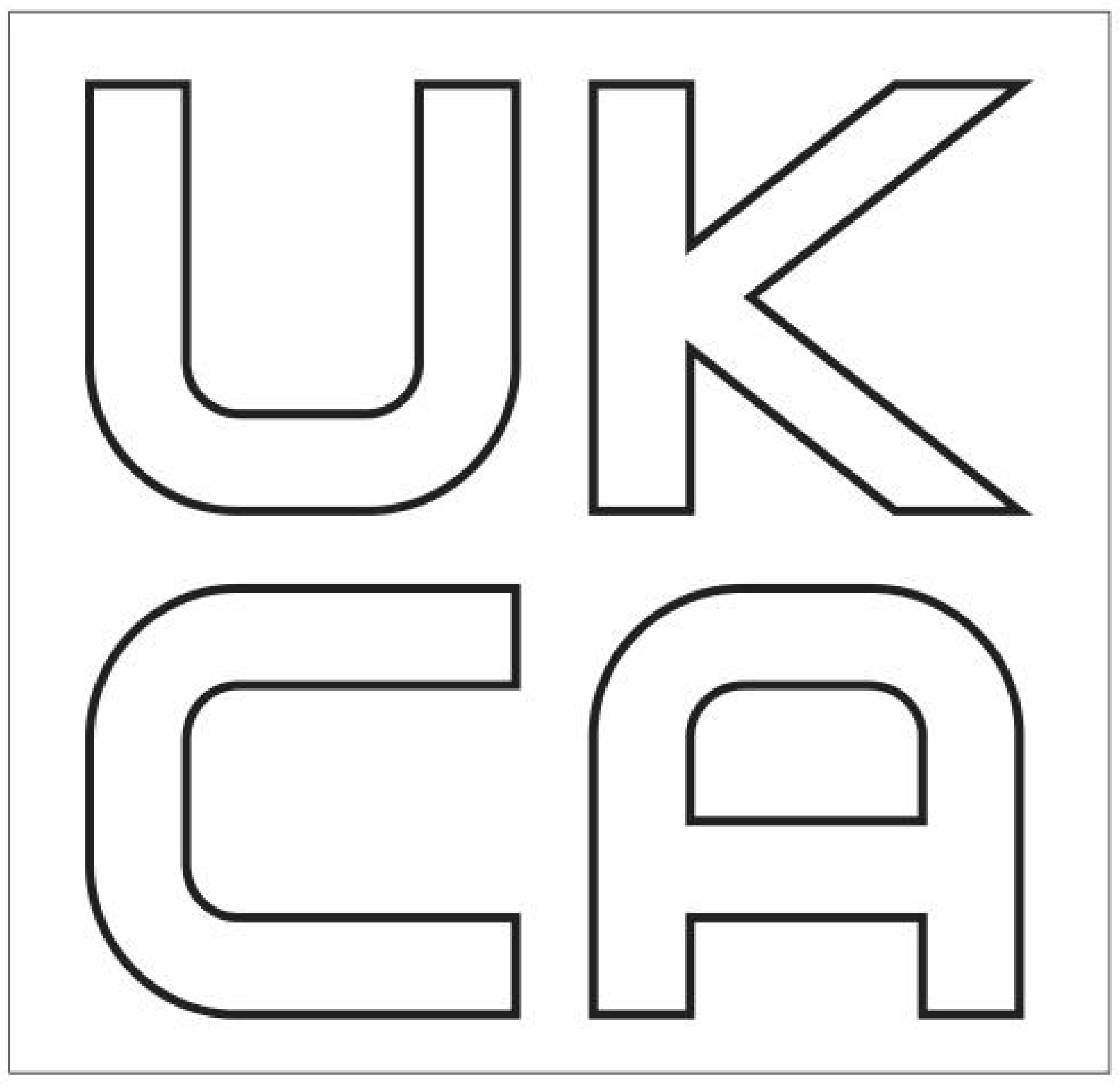
Furthermore, many such goods are completely untraceable, with no details of manufacturers provided anywhere: for example, an admittedly decent-quality pair of binoculars recently sourced by the author from Amazon has a meaningless name on the strap and no maker's details anywhere. Such anonymity makes it impossible to trace non-compliant goods back to their source and only raises suspicions about their quality or warranties.

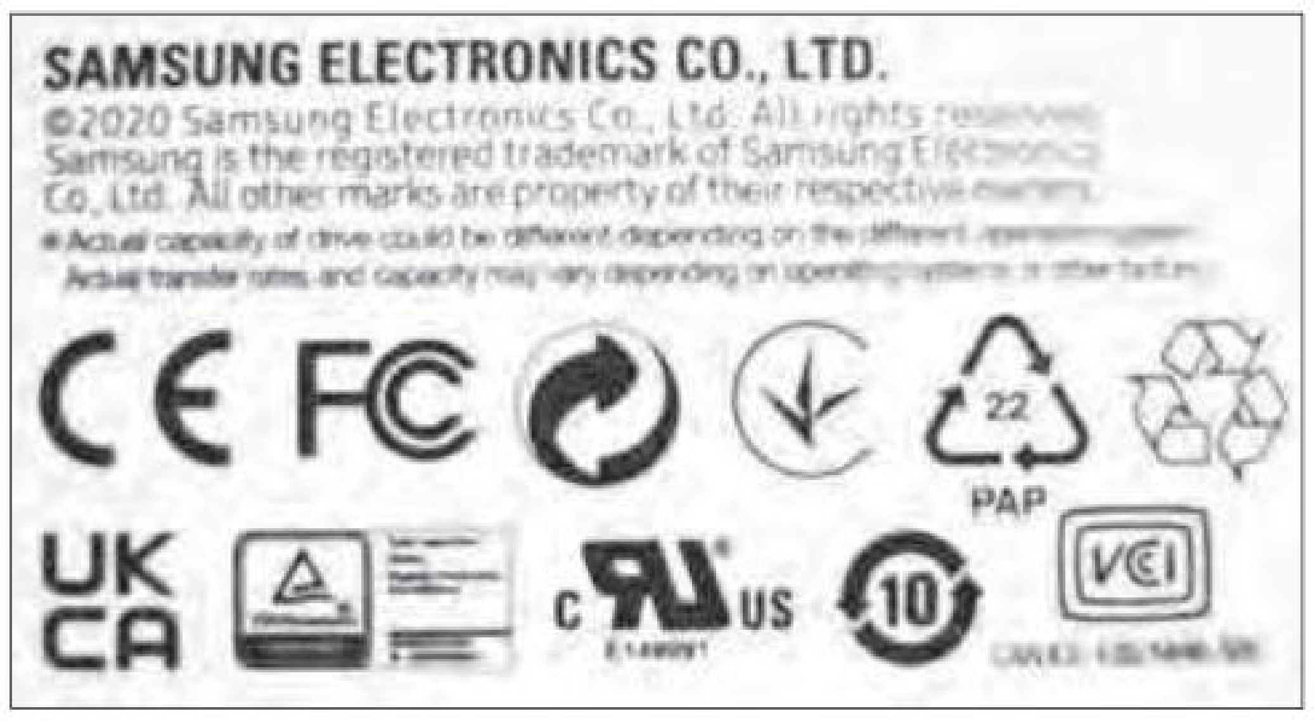
Sayonara to the CE Mark

Dodgy goods probably won't have an EU Certificate of Conformity either (asking for one is likely to be fruitless),



Above and below, the UKCA (UK Conformity Assessed) mark will apply for new stocks of items placed on the market in Great Britain from 1 January 2022.





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A UKCA and genuine CE mark appearing on a Samsung SSD in 2021.

and even if there was one, the writer would treat it with some scepticism anyway. It's not just the CE mark that some producers play fast and loose with, some electrical goods sold in the UK sometimes have familiar but bogus BSI (British Standards Institute) 'kitemark' logos too. Yet makers and importers get away with this deception and a myriad of phony products appear online in all the usual places.

Having stated there is no such thing as a recognised 'China Export' mark, the writer was genuinely shocked to see the idea given credence on some respectable-looking technical web sites. It is a simple rip-off of the genuine CE mark and anything that bears a phony CE mark should be given a wide berth or, at the very least, treated with extreme caution. Look especially closely at cheap imported mains adaptors, power cords and similar electrical gadgets, for example. These are often sourced by younger people online who may not realise that they are being duped into buying potentially dangerous goods.

Now that the United Kingdom has left the EU, the country is in the midst of introducing its own quality compliance symbol. Readers will gradually start to see the new UKCA (UK Conformity Assessed) mark, for *new* stocks of items placed on the market in Great Britain from 1 January 2022. In fact, it already appears on a Samsung Pocket SSD purchased by the author recently. Both solid and outline forms of the rather dull (and probably easily copied) logo will be seen. Also, UK Declarations of Conformity will start to appear with new goods in coming years. Due to the Brexit transition rules deal, the CE logo, not the UKCA symbol, still prevails in Northern Ireland for the time being. There is more information on the new UKCA at: **https://bit.ly/pe-oct21-ukca**

Buyer beware?

A cynic (or realist – take your pick) might suggest that 'CE' actually originates from the first truly pan-European language and should be interpreted as *Caveat Emptor* – Latin for 'Let the buyer beware'. (It's unlikely that a Roman first uttered this snappy phrase a couple of millennia ago, but it certainly has several centuries of use in English Common Law – see: **https://bit.ly/pe-oct21-cvl**)

Not-so-smart meters

Britain's gas and electricity suppliers are still pushing hard to get smart meters installed in our properties, and although the project roll-out seems to have been lost among all the disruption caused by Covid-19, the eye-watering cost of the programme continues to spiral upwards. Furthermore, UK consumers have now been warned of looming price increases from October, just as winter beckons, as utilities compete for supplies of gas and wholesale prices edge upwards. Back in 2019 the Department for Business, Energy and Industrial Strategy reckoned it would be at least another five years before the smart meter programme starts to deliver net cost benefits to consumers, but the programme has slipped behind and has been plagued by problems that ought to have been resolved by now.

Back in the December 2019 and January 2020 issues I outlined how British consumers were being pressured into installing smart meters in their homes, meters sometimes being used as bait to attract cheaper tariffs. It's a perverse distortion to suggest that smart meters are merely benign devices here to help us 'save money'. As I wrote in December 2020, this decade-old EU energy policy was intended to make the European energy market more resilient, combat climate change and (whisper) establish an 'internal market'. With all sorts of political problems looming with gas supplies in mainland Europe (including the controversial NORD2 pipeline from Russia to Germany, see Gazprom's website at: **https://bit.ly/pe-oct21-gaz**), the future of power transmission has never been less certain and control of much of the European mainland's gas supplies has been allowed to fall into Russian hands.

Smart meters are all about handling 'Demand Side Response' (DSR) which means 'encouraging' consumers to reduce consumption at times when capacity is limited. This may ultimately involve penalising consumers by charging more when power is consumed during times of low (cheap) supply. For example, when there is little solar or wind power available but the weather is wintry, so nuclear and fossil fuels are used. Or when there's too much air conditioning operating during summer periods.

Coaxing us to use less

Near real-time raw data is already captured that could easily show what power is being used, and when, by consumers, thanks to smart meters reporting it over the Smart Meter Wide Area Network (SM WAN) every 30 minutes or so. In the future we can expect to be nagged, either by text message or messages popping up on our 'In Home Displays' (IHDs) imploring us to reduce our demand. In the not-so-distant future we can certainly expect to see our behaviour being

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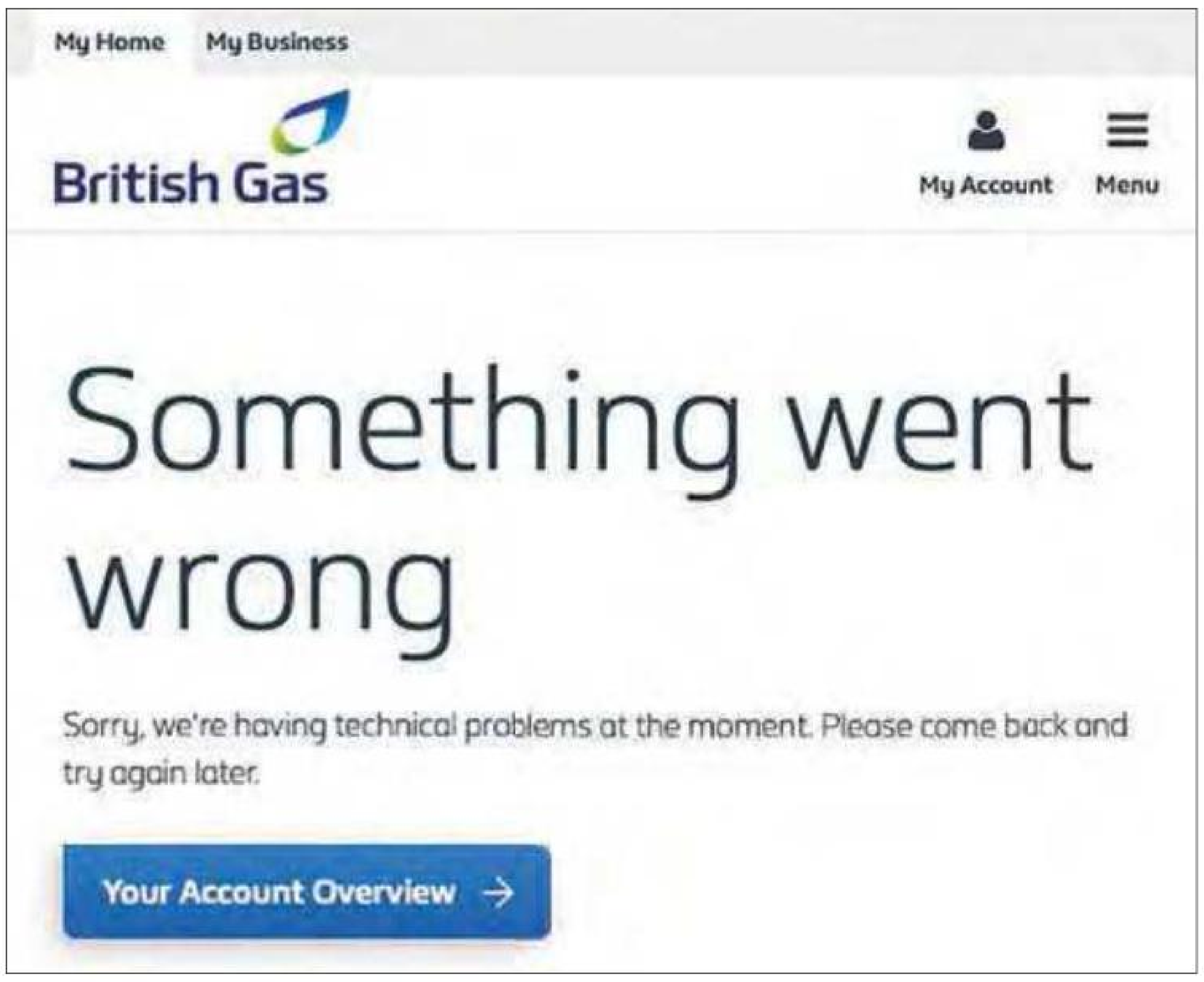

Something went wrong

Sorry, we're having technical problems at the moment. Please come back and try again later.

Says it all: a British Gas smart meter booking page goes 404.

modified as we become conditioned into using less gas and electricity this way, and instead use 'green alternative solutions'.

Some fundamental problems still exist with smart meter technology today, particularly first generation SMETS1 (Smart Metering Equipment Technical Specification) which may 'go dumb' or IHDs (In-Home Display) that stop working. Trying to change your supplier – which we are all being actively encouraged to do in order to beat the price rises – can open a whole new can of worms for consumers. If you're enjoying a lower-priced tariff, when that deal ends customers can expect a startling rise in costs when they face the new market prices.

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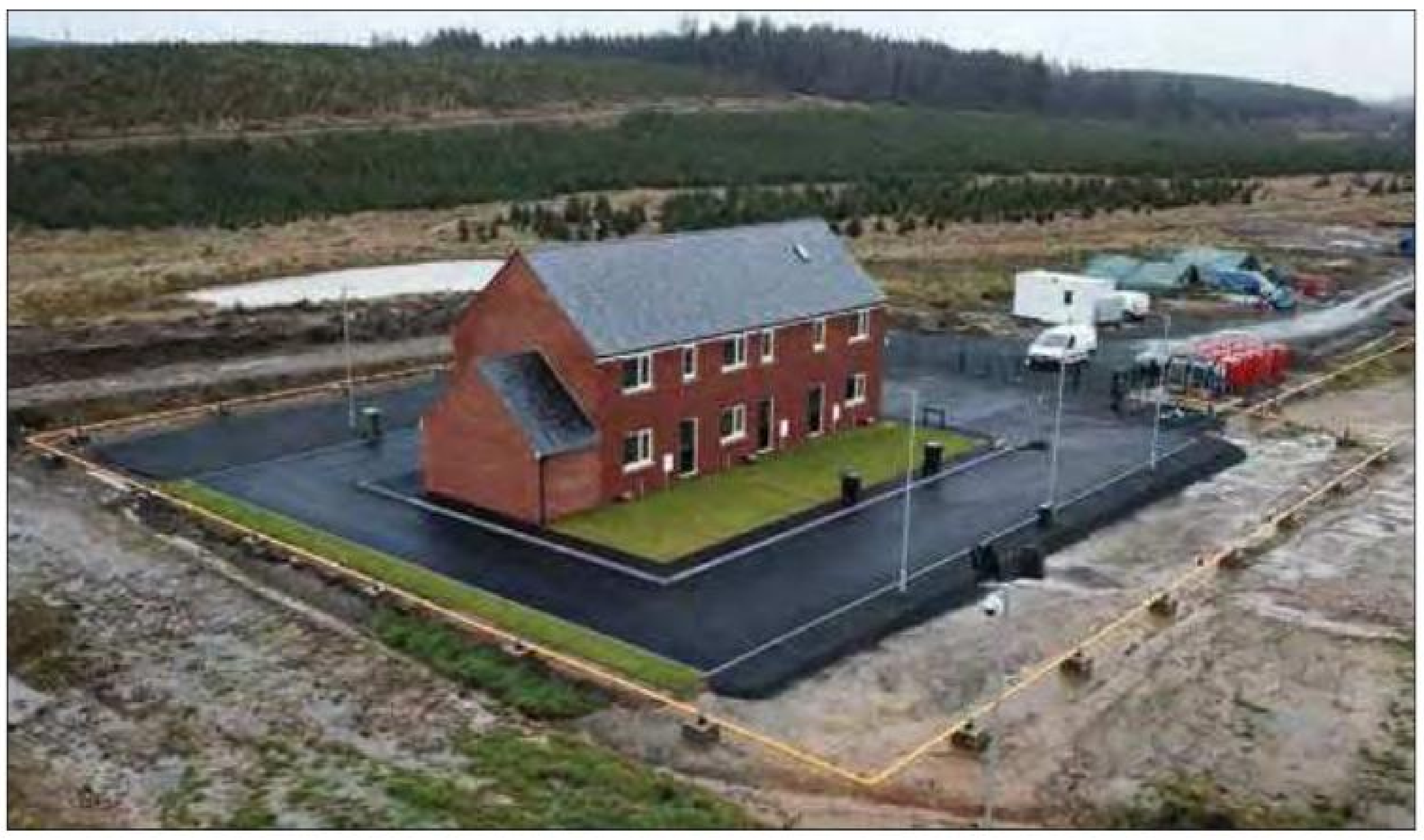

(Above) Early trials by H21.green are under way to test hydrogen as a source of heating in Spadeadam, Cumbria in the north of England. Note the yellow supply pipe around the test houses.

(Below) The houses are built on the appropriately named 'Hy Street'.

The British Gas smart meter revolution continues to clunk along mindlessly with sub-par meters and a hopeless online booking service. Our editor was sent an invitation, claiming: 'We're installing smart gas meters in your area. Our engineers are upgrading homes near you to the latest version of smart meters – the next generation SMETS2 meters, so you can keep control of your energy. Get in touch to make an appointment today – installation is free. Make sure you don't miss out. The sooner you get in touch, the quicker we can install your new meters.' Every link for this truly resistible offer led to a web page that is symptomatic of the state of the industry – as shown above, left.

All eyes are looking towards the eventual supply of hydrogen as one of the ultimate clean fuels and it's possible that domestic gas heating systems could be converted to run on hydrogen instead. But it's not trivial to change over, as the government has admitted that boilers (furnaces), pipes and smart meters themselves (!) would all need converting due to the chemical and physical differences between methane gas and hydrogen. Trials are underway by the consortium H21.green (**https://h21.green**) to build a hydrogen gas 'microgrid,' including blending hydrogen with natural gas, with a test site in Cumbria having three demonstration houses powered by hydrogen. More details on the YouTube video at: **https://youtu.be/GNIGJzbERg4**

Somehow, I suspect that although the power-gen industry may promise much, if the smart meter rollout is anything to go by, energy consumers will face a lot of delay and frustration for decades to come.

In earlier columns I wrote extensively about the upsurge of electric vehicles, notably made in China. Warnings have already been issued about vulnerabilities in some EV charger systems at home which could be prone to hacking. In Britain, it has been announced that by 2024 a North Lincolnshire motorway could become the first 'electric road' to power electric trucks, charging them from overhead cables in a way similar to how trams were powered more than a hundred years ago. What goes round comes round, but will there be enough electricity to meet this spiralling demand?

See you next month for more *Net Work!*

The author can be reached at:
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Mini WiFi LCD BackPack

As well as a colour touchscreen, another very handy feature to have in a microcontroller module is wireless communications. Wi-Fi is probably the most versatile method, as most homes and offices have Wi-Fi networks. Once the micro has Internet access, the list of things you can do with it explodes! This low-cost project uses an ESP8266-based module which is both powerful and inexpensive.

By Tim Blythman

While this BackPack has a plethora of potential uses, some of the most promising are in the area of home automation. This is a rapidly growing field, and it's getting much easier to implement.

Systems that can be built onto existing Wi-Fi networks are common, and little wiring is required. Our *D1 Mini-based LCD BackPack* makes adding a custom Wi-Fi-enabled touchscreen interface quite easy.

The D1 Mini

The D1 Mini is one of the smallest fully-contained Arduino-compatible microcontroller boards. And since it is based on the 32-bit ESP8266 microcontroller, it has a 2.4GHz Wi-Fi radio built-in.

The ESP8266 has very quickly become a favourite of both hobbyists and manufacturers. It appears in many commercial Wi-Fi products, including those used in home automation, such as smart Wi-Fi globes (lightbulbs) and smart mains switches.

Of the handful of commercial wireless home automation products we've tried recently, almost all of them were ESP8266-based.

This is one of the reasons for the continued popularity of the Arduino platform.

The D1 Mini is based on the ESP-12 module, which contains an ESP8266 microcontroller and a 4MB Flash IC. It also incorporates a CH340 USB-serial converter, a 3.3V regulator and a handful of passives. Twelve I/O pins are broken out for external use.

We used the D1 Mini in our *Clayton's GPS Time Source* (*PE*, April 2019). This connects to the Internet via Wi-Fi to simulate a GPS time source by retrieving accurate time from an NTP (Network Time Protocol) server. This is an example of a simple and useful data source that can be accessed via Wi-Fi.

The ESP8266 includes a 32-bit micro running at 80MHz and has 80kB of user-accessible RAM, so it is much more capable than many AVR-based Arduino boards. All the ESP8266 boards we have seen have at least 512kB of Flash memory; many have much more.

They are perfect for adding both Wi-Fi and a GUI (graphical user interface) to a small project. In particular, the ample Flash memory allows colourful graphics to be embedded and displayed on the screen.

To help you turn the *D1 Mini LCD BackPack* into something useful, we've created a demonstration program for it which shows off its Wi-Fi, graphical and touch features.

The program fetches accurate time and weather data from the Internet; the time comes from an NTP server, while the weather data comes from: **https://openweathermap.org/**

This data is displayed as a combination of text and images. The touch interface supplies a small number of user functions, such as setting the weather location and Wi-Fi network settings.

Circuit details

The Micromite and its various BackPack incarnations have been extremely popular, not just in their own right, but as a basis for numerous projects. We also published an adaptor to allow Arduino R3-compatible boards to drive 3.5-inch or 2.8-inch touchscreen LCDs (see *PE*, June 2020).

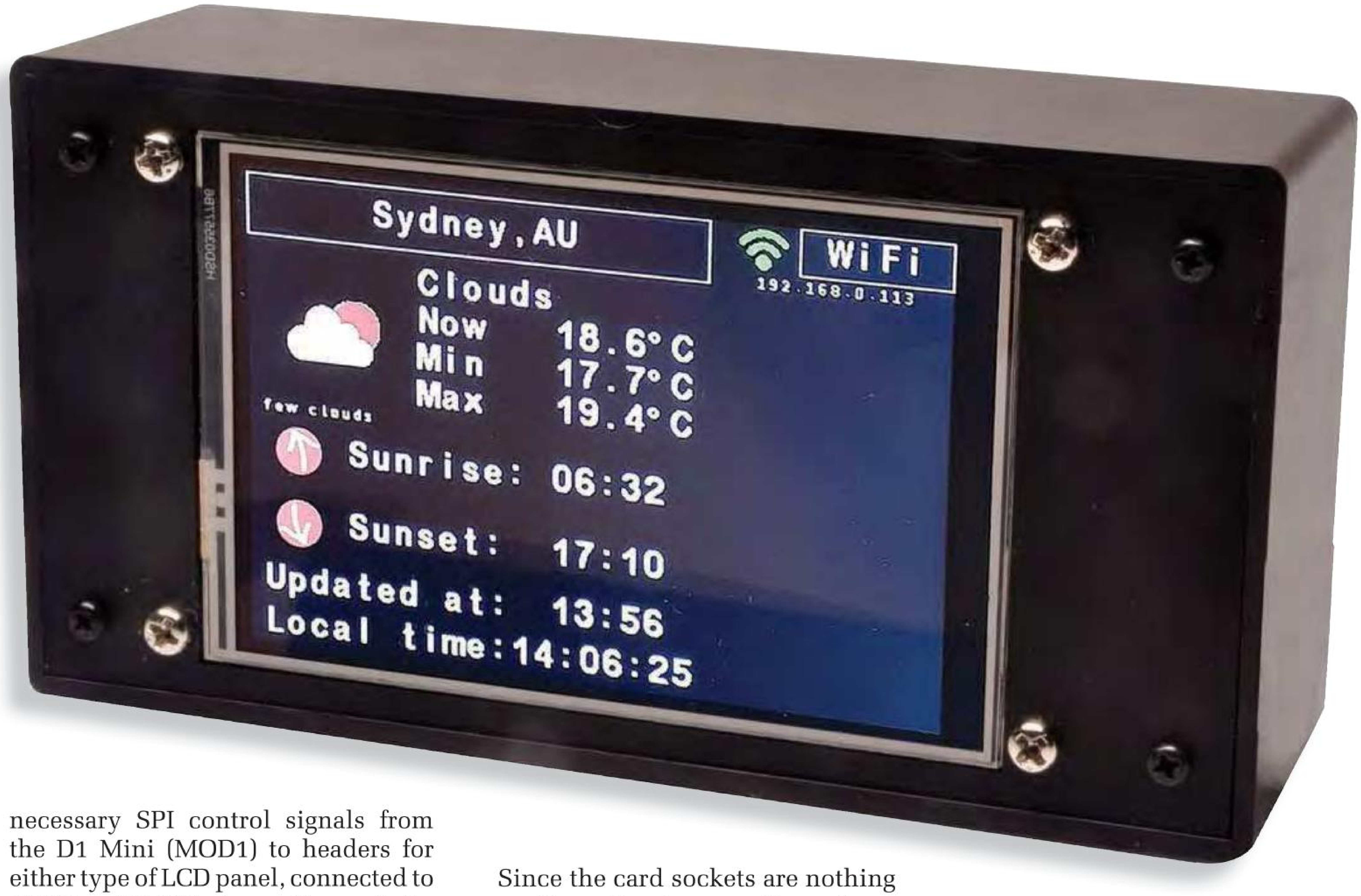
We thought it would make sense to use the same principle in designing a board to allow these types of touchscreen to be driven by a D1 Mini. Our demonstration software is designed for the 3.5-inch display, but the hardware also supports the smaller and slightly cheaper 2.8-inch displays.

Given the small difference in price, unless your application can't fit the 3.5-inch screen, that is the best option.

Fig.1 shows the circuit of our new *D1 Mini BackPack*. As you might imagine, there isn't a lot to it. It routes the

Features and specifications

Display	3.5-inch 480x320 colour LCD
Processor	ESP8266, 160MHz 32-bit
Flash memory	4MB
RAM	80kB
Interface	Touch panel
Other features	Wi-Fi, remote (OTA) reprogramming, prototyping space, 12V power supply



necessary SPI control signals from the D1 Mini (MOD1) to headers for either type of LCD panel, connected to CON1 and CON1a (mounting pads for CON1a are provided in two different locations, to support the two different screen sizes).

The hardware SPI signals on the D1 Mini are at pins D5 (SCK), D6 (MISO) and D7 (MOSI). Due to the way that the pins are mapped, these actually correspond to general-purpose I/O (GPIO) pins that are numbered 14, 12 and 13 respectively.

We've used the numbers with the 'D' prefixes as this is how the D1 Mini is labelled. See Table 1 for more information about the curious and slightly confusing numbering used on this board.

The CS pin for the LCD is wired to pin D8, and D/C (data/command) is wired to pin D4. Due to the low number of pins available, the RST pin for the LCD is wired to RST pin on the D1 Mini; this works well and saves a pin.

The separate CS pin for the touch controller is connected to pin D3.

Although the panel includes an SD card socket, we've also opted to add a micro SD card socket to our board. There are two reasons for this: the PCB traces to the SD socket on the LCD panel are quite circuitous, which makes the card more susceptible to interference. Also, when the SD card is fitted, it protrudes quite a bit.

The micro SD card is smaller, and when attached to the board is less likely to interfere with the display and mounting hardware. The CS pins of both the SD and micro SD card sockets are connected to the D1 Mini's D2 I/O pin.

Since the card sockets are nothing more than direct connections, these pins can be shared, as long as there isn't a card in both sockets at the same time. Indeed, if you don't need the micro SD card feature, I/O pin (D2) can be reused.

We've also added a DC jack and a 7805 5V linear regulator. Thus, if 12V is needed for operating lights, motors or relays, a single 12V supply (such as a DC plugpack) can be provided. The regulator will work with input voltages down to around 7V.

When running off a 12V supply, the regulator dissipates around 2W and gets quite warm.

You might like to substitute our *Switchmode 78xx Replacement* from the August 2021 issue if you need to draw more current from the 5V rail, or just to reduce the heat output.

There are four bypass capacitors on the PCB; two for the 5V regulator and two for the micro SD card socket. We've provided PCB pads that suit both 3216 (1206 imperial) SMD or 0.2-inch-pitch through-hole parts.

Four sets of jumpers are provided. These can be left off if a feature is not needed, for example, if the I/O pins are needed for another application.

JP1 can be used to connect the MISO pin for the LCD (which is not usually needed) to the SPI bus. We have found that some 3.5-inch displays do not behave correctly; hence, we have not connected these two lines directly. For our demo application, and indeed most applications, it can be simply left open.

JP2 can be used to connect the LCD backlight to the 5V rail or I/O pin D0. We imagine that most applications will be powered from fixed wiring, so the necessity to turn off the backlight using D0, to save power, is reduced.

The centre pin of JP2 goes to a pair of MOSFETs and two pull-up/pull-down resistors that provide the high-current drive needed for the backlight LEDs. On the 3.5-inch display, this can be up to 250mA. An identical arrangement is used on the Micromite BackPacks.

For our sample application, JP2 is set to the 5V position.

JP3 and JP4 are the remaining connections and go to the touch interrupt pin (TIRQ) and SD card detect switch (SDCD). These can be set to connect either signal to pin D0 or D1.

The connection to D0 is brought through a series 1kΩ resistor, as this pin is actively driven high at power-up. This prevents excessive current flowing if the pin D0 is used for the SD card detect function, as the pin is simply shorted to ground by a switch inside the card socket.

To help the card-detect function, a 47kΩ pull-up resistor is also provided, as pin D0 does not have an internal pull-up. These two resistors can be changed if you require a different role for this I/O pin.

To fill out the substantial space that is left on the PCB that's sized to suit the touchscreens, we've provided a large prototyping area that isn't shown on the circuit diagram.

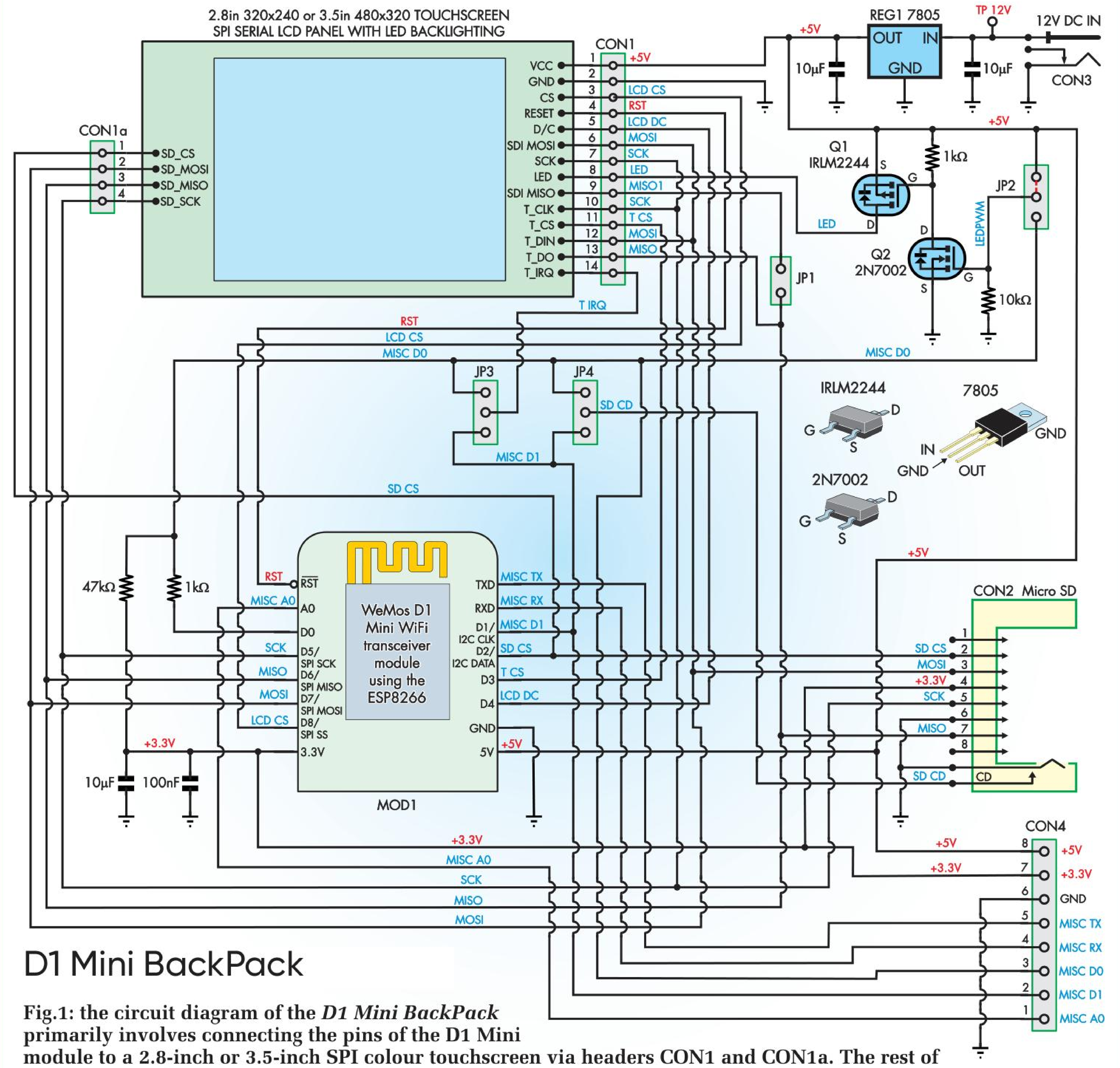

2.8in 320x240 or 3.5in 480x320 TOUCHSCREEN
SPI SERIAL LCD PANEL WITH LED BACKLIGHTING
CON1
VCC
GND
CS
RESET
D/C
SDI MOSI
SCK
LED
SDI MISO
T_CLK
T_CS
T_DIN
T_DO
T_IRQ
1
2
3
4
5
6
7
8
9
10
11
12
13
14
+5V
LCD CS
RST
LCD DC
MOSI
SCK
LED
MISO1
SCK
T CS
MOSI
MISO
CON1a
SD_CS
SD_MOSI
SD_MISO
SD_SCK
REG1 7805
OUT
IN
GND
+5V
TP 12V
12V DC IN
10µF
10µF
CON3
+5V
Q1
IRLM2244
S
G
D
1kΩ
LED
Q2
2N7002
D
S
G
10kΩ
JP2
LEDPWM
JP1
T IRQ
RST
LCD CS
MISC D0
MISC D0
JP3
JP4
SD CD
MISC D1
SD CS
IRLM2244
G
D
S
7805
IN
GND
OUT
GND
2N7002
G
D
S
47kΩ
1kΩ
RST
MISC A0
SCK
MISO
MOSI
LCD CS
+3.3V
10µF
100nF
WeMos D1 Mini WiFi transceiver module using the ESP8266
RST
A0
D0
D5/ SPI SCK
D6/ SPI MISO
D7/ SPI MOSI
D8/ SPI SS
3.3V
TXD
RXD
D1/ I2C CLK
D2/ I2C DATA
D3
D4
GND
5V
MISC TX
MISC RX
MISC D1
SD CS
T CS
LCD DC
+5V
MOD1
+5V
CON2 Micro SD
SD CS
MOSI
+3.3V
SCK
MISO
SD CD
CD
+3.3V
MISC A0
SCK
MISO
MOSI
CON4
+5V
+3.3V
+5V
+3.3V
GND
MISC TX
MISC RX
MISC D0
MISC D1
MISC A0
D1 Mini BackPack

Fig.1: the circuit diagram of the *D1 Mini BackPack* primarily involves connecting the pins of the D1 Mini module to a 2.8-inch or 3.5-inch SPI colour touchscreen via headers CON1 and CON1a. The rest of the circuit is a basic power supply, a backlight control section, some jumper options, a convenient micro SD card socket and a header which gives you access to the few remaining free pins of the micro.

This consists of 17 rows of eight pads which are arranged to fit a 0.3-inch DIL packaged device, although it can be used for other types of components.

An adjacent row of headers breaks out the spare signals from D1, D0, TX, RX (UART) and the single analogue input A0, along with strips of pads to connect to ground (GND), 5V and 3.3V.

The PCB itself follows the theme used for both the *Micromite BackPack V3* (see *PE*, August 2020)and the *3.5-inch Touchscreen Arduino Adaptor*. The PCB can be slightly shortened if using a 2.8in LCD panel.

Two sets of mounting holes allow either size of panel to be securely mounted with 3mm machine screws and tapped spacers.

Construction options

There are a few options for you to consider during assembly. MOD1 can be permanently mounted to the PCB by soldering it directly, or you may like to make it removable by using suitable header sockets.

In the latter case, you will probably need to increase the space between the PCB and LCD panel, to give the extra height required when using these headers. We created some spacers for the LCD by soldering a row of male headers to female headers.

Of course, you may also be restricted by the space available for mounting if you are planning to fit the unit in a wall cavity or similar. In that case, soldering MOD1 in place is a good idea. We'll describe the assembly with MOD1 fixed in place, although it will be the last step.

If you don't need a micro SD card socket then CON2 and its two associated capacitors can be left off. But note that they will be much trickier to install later, so it's best to fit them anyway if there's any chance you'll be needing the socket.

If you are planning only to use the 2.8-inch display, then you can cut or snap off the right-hand portion of the PCB before starting assembly. But there's no harm in leaving the PCB whole if you have space.

To avoid inhaling fibreglass dust, trim the PCB outdoors and wear a face mask. Carefully score the four PCB traces to prevent them from tearing. With flat-nosed pliers, flex the PCB at the three places it's joined; it should snap at the naturally weak points.

You should also file or sand any rough edges left after snapping; again, be careful to avoid inhaling the dust.

Fitting the components

The *D1 Mini BackPack* is built on a double-sided PCB coded 24106201, measuring 99 x 54.5mm and available from the *PE PCB Service*. Refer to the photos and PCB overlay diagram (Fig.2) during assembly. There are a few surface-mounted parts to install; we recommend using a fine-tipped, temperature-adjustable soldering iron, solder flux, tweezers, solder braid (wick) and a magnifier of some sort.

Fit the micro SD card socket first, as it has the closest pins. It has a pair of locating pins, so it is straightforward to get it into position.

Apply flux to its pads and place the part, checking that the pins line up. Turn up the iron a little and solder one of the larger mechanical pads to fix it in place.

Solder the electrical pins by adding a small amount of solder to the iron, then touch the tip of the iron to each pin. The flux should induce the solder to run off and form a clean fillet. If you make a solder bridge, leave it for now and ensure that the remaining pins are connected.

Now go back and remove any bridges using the solder braid (wick). Apply more flux to the bridged pads, then push the braid against the excess solder with the iron. Once it melts, slowly draw the braid away from the pads.

With the electrical pins complete, the remaining mechanical pads can be finished. Leaving these until last will make it easier to completely remove the part if this is necessary. Apply more flux if necessary, and don't forget to turn the iron down to a setting for regular components afterwards.

The two SOT-23 package transistors are the smallest parts but have more space around their leads, so fit them next.

Check the markings to ensure that Q1 and Q2 are not mixed up. Q1 should be marked with a code that starts with an 'X' while Q2 may be marked 72, 702 or possibly something else depending on the manufacturer (these codes are tiny, so you will need a magnifier to read them).

A good process for surface-mounted components is to apply flux to the PCB pads and load the tip of the iron with a small amount of excess solder. Hold the part in place with tweezers and apply the iron to one lead only.

If it is not flat and square, adjust it until it is. Then solder the other leads.

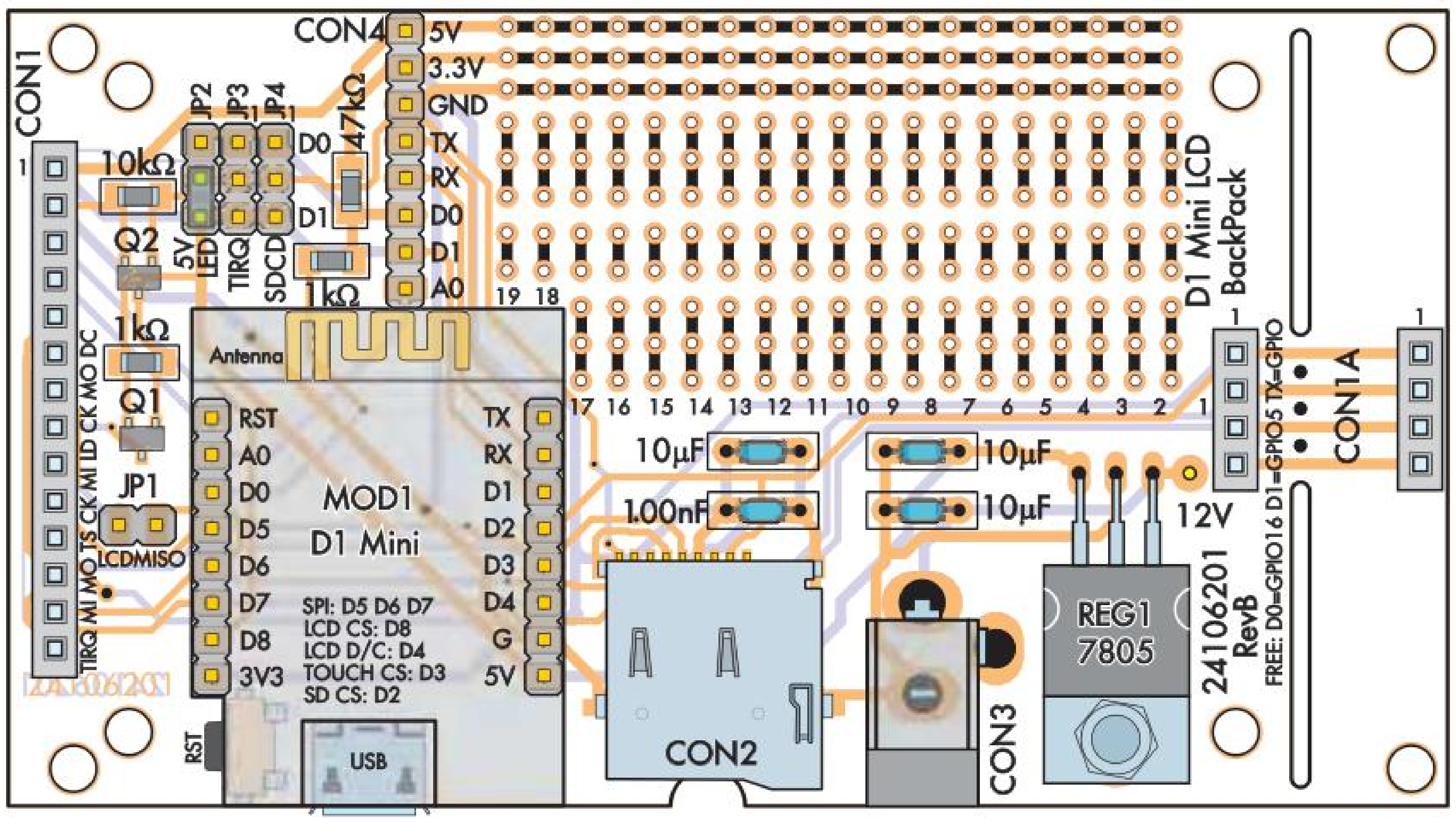
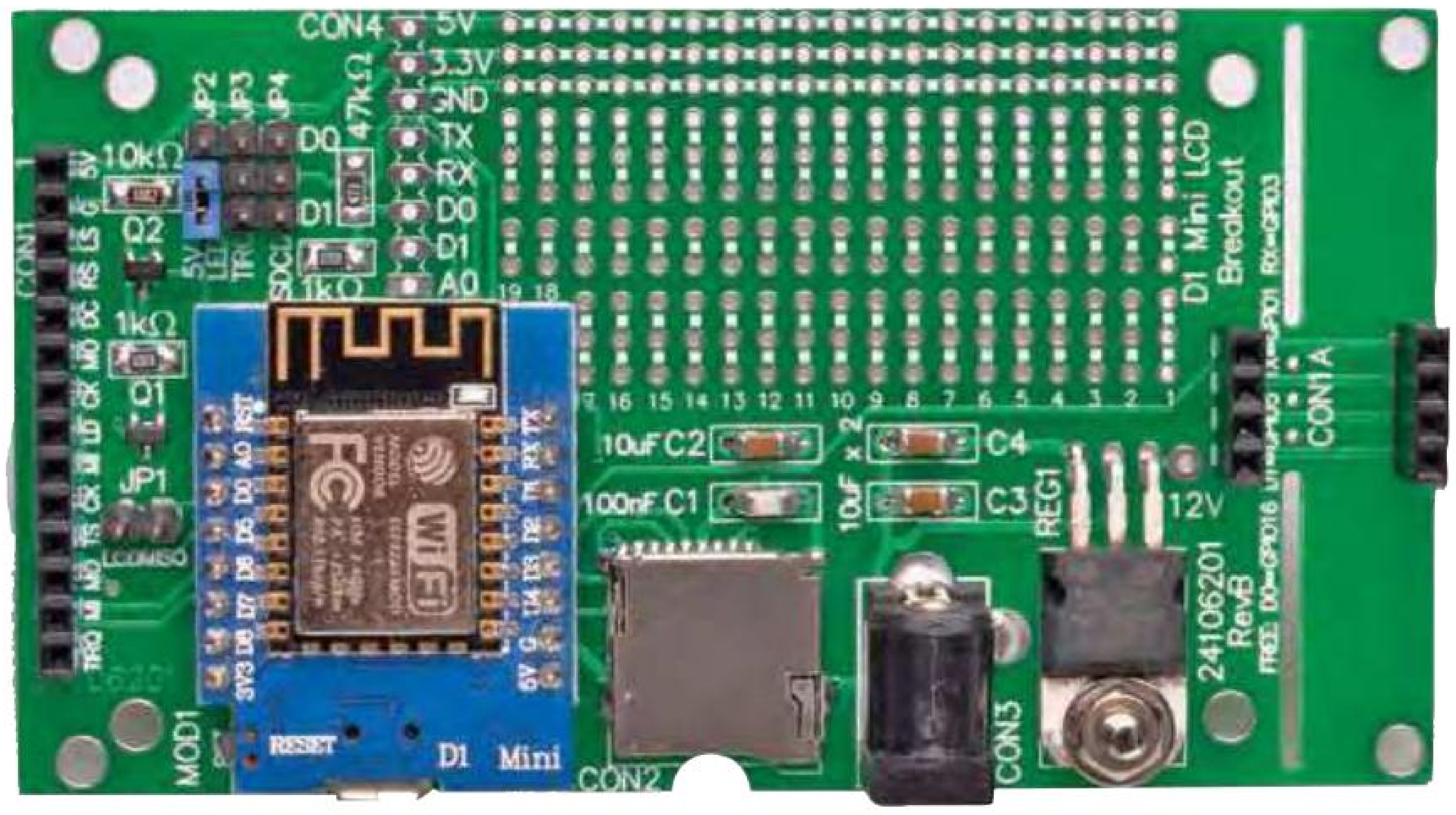


Fig.2: use this PCB overlay diagram and the matching photo below as a guide during assembly. There aren't all that many components; so as long as you take care with the SMDs, you should have it up and running in no time. Pretty much all the components are obscured by the touchscreen once it is fitted. For that reason, you might want to mount external I/O header CON4 on the reverse side.



Now that the part is secure, the solder fillets can be tidied up. This can be as simple as applying some extra flux to the solder, then touching it with the iron.

There are four resistors to be fitted; install these next, ensuring the correct values are used, as per the silkscreen and Fig.2.

If you are using through-hole capacitors, then solder and trim as per standard through-hole procedure. Follow the above process for surface-mounted parts.

Place the 100nF capacitor first; it will possibly be smaller than the other capacitors and is closest to the micro SD card socket. Repeat with the remaining capacitors, ensuring they are flat and square.

Bend the leads on REG1 down 90° about 6mm from the body and place them in the PCB pads. Fit the machine screw and affix the washer and nut; if this is done before soldering, then you can be sure that the regulator is situated correctly. Now solder the leads of REG1 and trim the excess.

Jumpers and headers

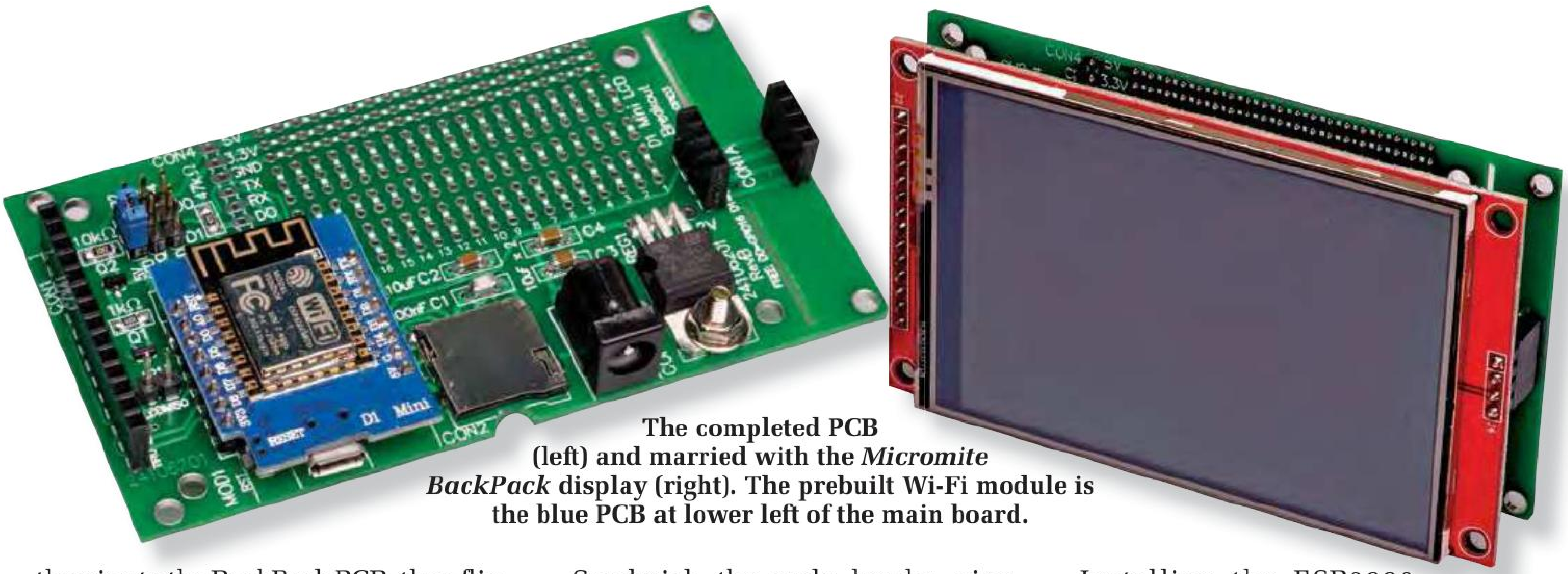
It is easier to fit JP1-JP4 before CON1 and CON1A. Slot JP1 in place and solder one pin. If it is not square, then you can hold the header by the other pin and adjust it while remelting the solder. When you are satisfied that it is flat and flush, solder the other pin.

To keep JP2-JP4 aligned, push them all into the female headers that will be used for CON1 and CON1A. As for JP1, solder one pin of the group, then adjust to be level and square before soldering the remaining pins. Then unplug the female headers.

If you are planning to use the SD card socket on the LCD, then you will need to fit CON1A, at a location depending on whether you plan to use the 2.8-inch or 3.5-inch display. Or you can fit both. Even if you don't plan to use this SD card socket, the extra headers help to secure the boards mechanically and align them. So it's a good idea to fit them.

Many LCD panels do not have the four-pin header fitted, so this will need to soldered too. The best way we've found to fit all the LCD headers is to plug the four-pin (male and female) headers together, then attach the 14-way female header to the LCD panel.

Rest the LCD panel face-down and place the four-way headers in their pads, with the male pins facing down (matching the orientation of the 14-way header). Then rest the PCB on top and line up the pins with their holes. Solder



The completed PCB (left) and married with the *Micromite BackPack* display (right). The prebuilt Wi-Fi module is the blue PCB at lower left of the main board.

the pins to the BackPack PCB, then flip the assembly over and solder the male pins into the LCD panel.

This process ensures that all the pin headers and sockets are as square as possible, making it easier to change out the LCD panel if necessary; say, if you are swapping from the 3.5-inch to the 2.8-inch variant.

By the way, you might notice that we're mounting the touchscreen rotated by 180° in comparison to our previous *Micromite BackPack* projects. As the LCD and touch drivers are capable of rotating the display in increments of 90°, this does not cause any problems later.

Next, solder the DC jack. This may need some extra heat on the iron, and the large pads will need a fair amount of solder. Like the other parts, you can solder one lead, check that the part is oriented correctly, then solder the remaining pins.

The final component is MOD1, the Di Mini. Many of these (such as Jaycar's XC3802) come with an assortment of loose headers. We are assuming that the D1 Mini is fitted with male header pins underneath (in a fashion that would allow it to be used in a breadboard), so if you have different headers fitted, you may need to change them.

If you wish to remove the D1 Mini in the future, this will mean that the PCB should be fitted with header sockets. As noted earlier, you may need to find a way to space the LCD panel to account for the space these headers take up.

We'll assume you're soldering the D1 Mini directly to the PCB, as we did.

Sandwich the male header pins between the MOD1 and the PCB and tack a few pins from the top, then flip over and tack a few pins on the bottom. Check that everything is square and correct. You may also like to check that a USB cable can be plugged in.

Even if you don't plan to power the unit from USB, it's a good idea to leave it accessible for programming. Once you are happy with this, solder the remaining pins and trim them.

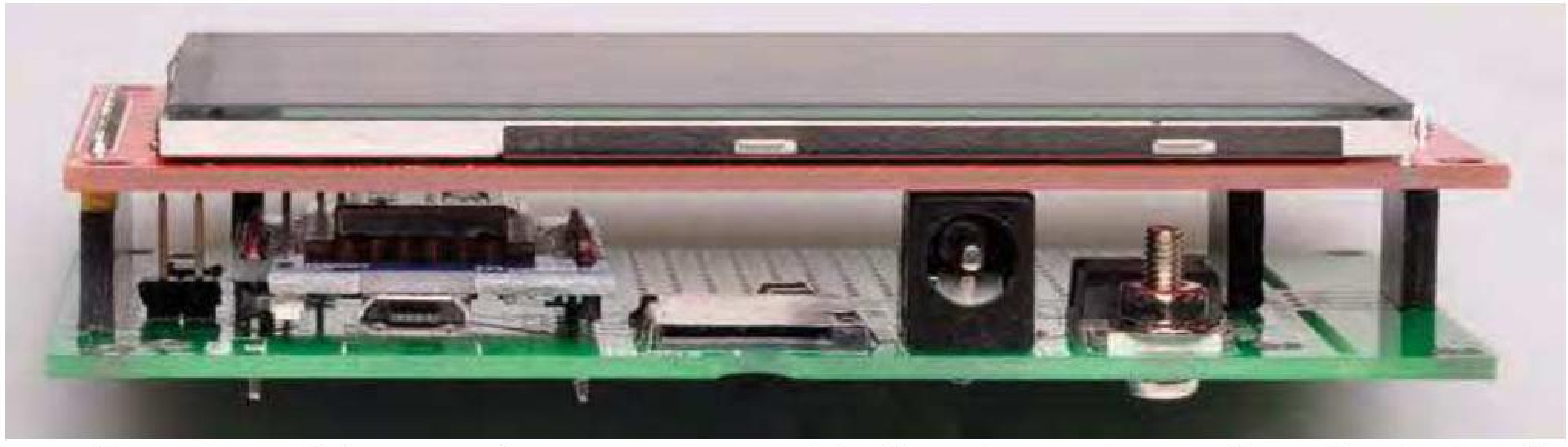
For the demonstration software we have written, only one jumper is needed, for JP2, on the 5V side. See the photos and overlay to check the position to fit it.

The final step to a functional unit is to fit the LCD panel. Plug the 3.5-inch LCD into CON1 and CON1A. Installation in, say, a box or wall cavity, will require further steps, but these will be specific to your project. We'll look at mounting options once the unit is operational.

To secure the LCD panel, attach the tapped spacers to the front of the PCB with machine screws from behind, then slot the LCD panel into the headers and secure it with the four remaining machine screws from the front.

Software

To make use of our software, you'll need the Arduino IDE and the ESP8266 Board file; we'll assume you're familiar with the IDE (Integrated Development Environment). It can be downloaded from: **www.arduino.cc/en/software** We're using version 1.8.5; you should use this or a later version.



Another view of the way the PCB mates with the *Micromite BackPack* – it simply plugs into the 14-pin header socket (CON1) at extreme left and the four-pin socket (CON1A) at right. Power is supplied via the DC socket (CON3); alongside is the microSD card socket (CON2) with the USB socket under the Wi-Fi module.

Installing the ESP8266 add-on for the Arduino IDE requires adding the following URL to the Additional Board Manager list (found under File > Preferences): **http://arduino.esp8266.com/stable/package_esp8266com_index.json**

With the URL added, the ESP8266 add-on can be installed by opening the Boards Manager (Tools > Board > Board Manager), searching for ESP8266 and clicking 'Install'. This can take a while as it is a complete toolchain and board support files.

You may also need USB-serial drivers for the CH340 used on the D1 Mini. (Note that we used the drivers from here for a previous project: **https://bit.ly/pe-oct21-ch340**.)

The D1 Mini corresponds to the 'LOLIN (WEMOS) D1 R2 & Mini' in the Arduino Tools > Board Menu. Ensure that you have selected this and also selected the correct serial port.

Unzip our sketch to your Arduino sketch folder and open it with the IDE. There are no external libraries needed; the Wi-Fi libraries used are included with the ESP8266 board download. There are some LCD-specific library files that we have included in the sketch folder.

As with any project which uses Wi-Fi, there needs to be a means to select a Wi-Fi network and enter the network password. Many ESP8266 projects simply hard-code this into the sketch itself, but that's a bit crude.

Our sketch is a bit smarter. If it detects that no Wi-Fi network has been set, it scans for nearby networks and presents a list for the user to choose from. The user can then enter the password; the settings are saved to non-volatile storage. The result is a much friendlier end-product.

Thus, no Wi-Fi settings in the sketch need to be changed before uploading; these can all be set later.

OpenWeatherMap

One feature of our demo program is to retrieve weather information and display it on the LCD screen. This data comes from the **openweathermap.org** website. Although it is free to use this data, an account is required. This is used to limit free access, and also to provide access to more data for paid accounts.

An email address is needed to set up an account; just enter your details here: **https://home.openweathermap.org/users/sign_up** and then an email will be sent with a confirmation link; after clicking this, you'll receive a second email.

This second email contains an API key, which is a hexadecimal code our sketch needs to access OpenWeatherMap data (see Fig.3). There is an option to generate further API keys from your OpenWeatherMap account.

The free API key allows a limited number of accesses per day, with paid accounts allowing more frequent access to more detailed data.

Details of this are provided at: **https://openweathermap.org/price**

In any case, the free account and API key are sufficient for us to get a modest amount of data updated at a useful rate.

This needs to be set in the sketch before upload. Look for the line defining the OWM_API_KEY in the main sketch file and change it to the key you've been given. It should be surrounded by quote marks.

Now we can upload the sketch to the D1 Mini, by pressing the Upload button on the IDE. The compilation and upload process may take a minute or two, after which the LCD should clear.

The sketch

A lot of the sketch is dedicated to providing control of the LCD and a useful user interface, including a GUI routine which displays and monitors things such as the buttons and on-screen keyboard.

The sketch uses two sources of Internet data to update its display. The first of these is NTP (Network Time Protocol) data for the current time. Since NTP only provides the time as UTC (similar to GMT), a timezone offset is needed to calculate and display the actual local time.

Fortunately, the OpenWeatherMap data includes timezone information. It is also used to show things such as the current and forecast temperatures and graphics representing these. Sunrise and sunset times are shown too.

The time is pulled from the NTP server hourly, with the D1 Mini's internal timer being used to keep track of time in between. The weather data is updated every 10 minutes.

Operation

After the sketch is uploaded, you can open the serial monitor to get debugging information.

Parts list – Mini Wi-Fi LCD BackPack

1 double-sided PCB coded 24106201, 99 x 54.5mm available from the *PE PCB Service*
1 UB3 Jiffy Box
1 laser-cut lid to suit UB3 Jiffy box for 3.5-inch screen (optional) coded MMBP-LID-35 available from the *PE PCB Service*
1 D1 Mini development board (MOD1) [Jaycar XC3802 or similar]
1 14-way female header socket (CON1)
1 4-way female header socket (CON1A)
2 8-way female header sockets (to make MOD1 pluggable; optional)
1 3.5-inch SPI LCD touchscreen with ILI9488 controller [eg, Silicon Chip Cat SC5062]
1 4-way male header (usually comes with the touchscreen)
1 2-way male header (JP1)
3 3-way male headers (JP2,JP3,JP4)
4 jumper shunts (JP1-JP4)
1 SMD micro SD card socket (CON2)
1 PCB-mount DC jack socket, ID to suit plugpack (usually 2.1 or 2.5mm) (CON3)
1 M3 x 10mm panhead machine screw, hex nut and washer (for REG1)
8 M3 x 6mm panhead machine screws
4 12mm-long M3 tapped spacers (or longer if mounting MOD1 on sockets)

See PE August 2020 for details of building the V3 Micromite BackPack. The V3 PCB is available from the PE PCB Sevice.

Semiconductors
1 7805 5V 1A linear voltage regulator, TO-220 (REG1)
1 IRLML2244TRPBF P-channel MOSFET, SOT-23 (Q1)
1 2N7002 N-channel MOSFET, SOT-23 (Q2)

Capacitors
3 10µF 16V X7R SMD ceramic, 3216 (1206) size or through-hole equivalent
1 100nF 50V X7R SMD ceramic, 3216 (1206) size or through-hole equivalent

Resistors (all SMD 3216/1206 size, 1%)
1 47kΩ (Code 473/4702) 1 10kΩ (Code 103/1002) 2 1kΩ (Code 102/1001)

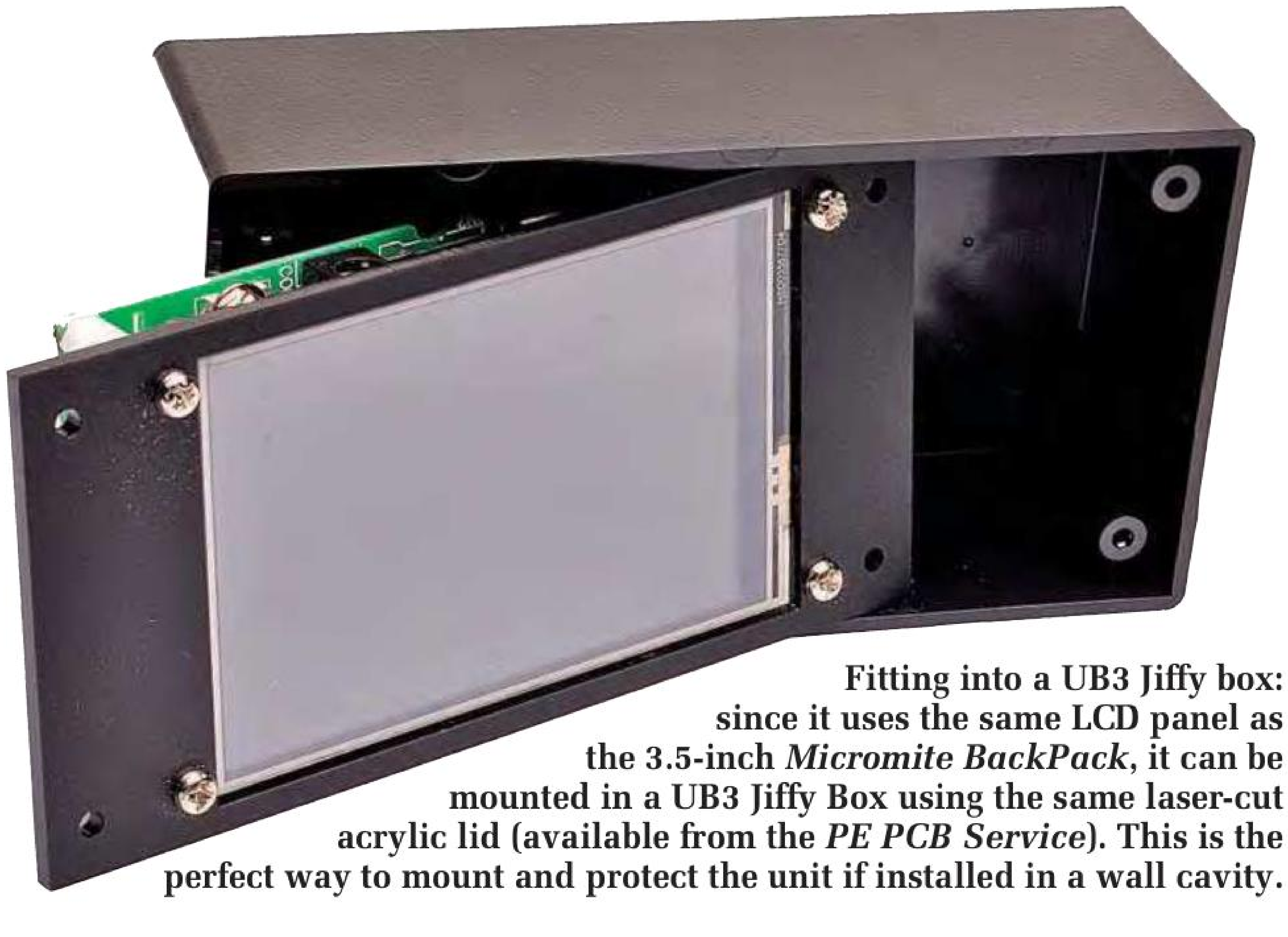
On the LCD, a message 'Scanning...' will appear, after which a list of Wi-Fi network names (SSIDs) will appear. Tapping on one will result in a prompt to enter the password using an on-screen keyboard.

This will be followed by a prompt to enter a location. This is the location used by the sketch to query OpenWeatherMap. We found a simple 'Sydney' was sufficient to get accurate data for our location in Australia, but if, say, you lived in Sydney, Nova Scotia, you might need to be more specific.

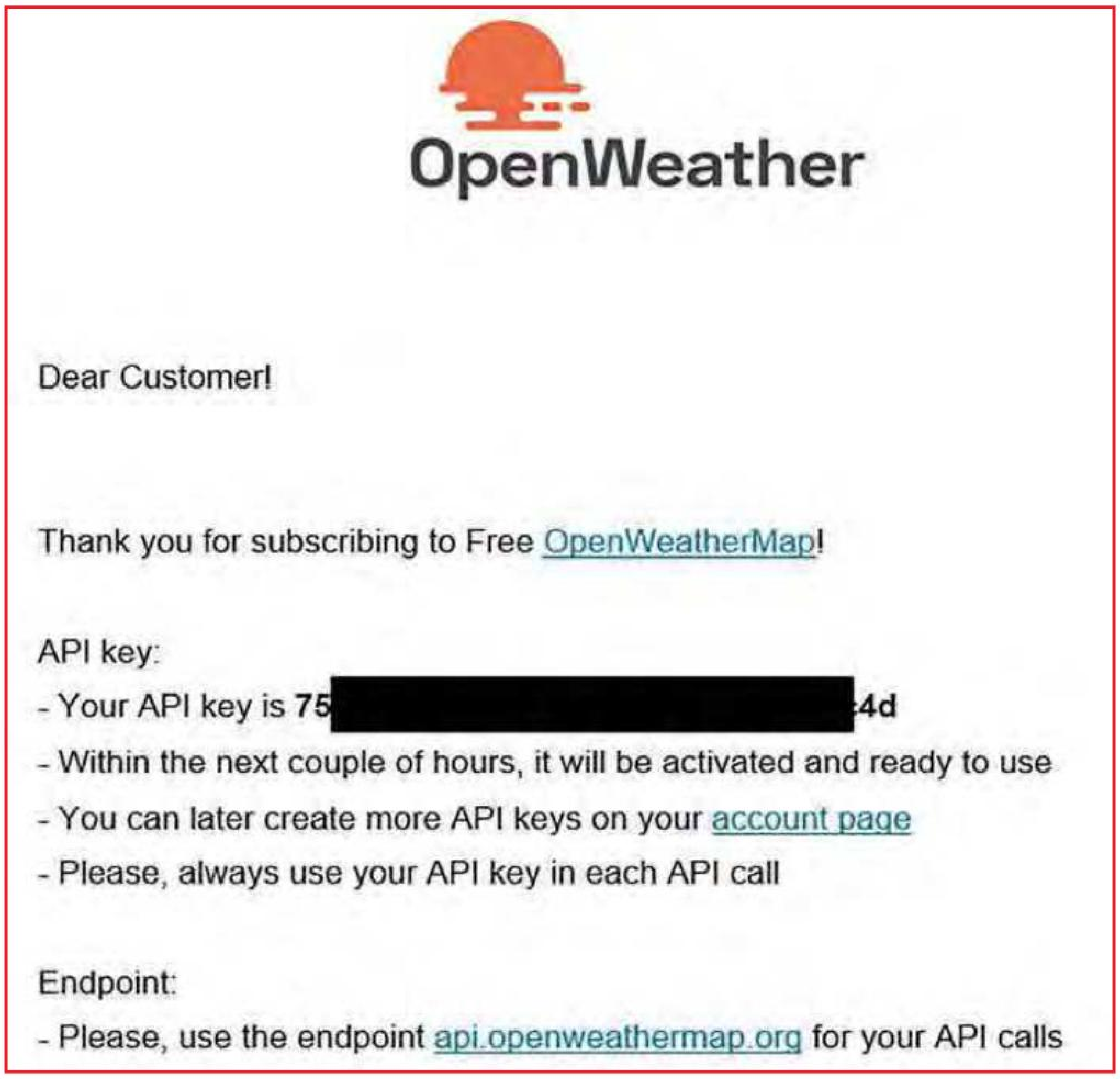
Entering 'Melbourne' displayed data more consistent with Melbourne, Florida than Melbourne, Victoria. 'Melbourne, AU' appeared to provide the correct data.

If you aren't sure, open the Serial Monitor and watch the displayed info; a lot of data is output for debugging. The data retrieved from OpenWeatherMap will appear as a single, long line. Information such as the latitude, longitude or country can be used to check that you have the correct location.

User information (such as Wi-Fi network and location) is saved in non-volatile storage. The ESP8266 doesn't have dedicated EEPROM, but



Fitting into a UB3 Jiffy box: since it uses the same LCD panel as the 3.5-inch *Micromite BackPack*, it can be mounted in a UB3 Jiffy Box using the same laser-cut acrylic lid (available from the *PE PCB Service*). This is the perfect way to mount and protect the unit if installed in a wall cavity.



Dear Customer!

Thank you for subscribing to Free OpenWeatherMap!

API key:

- Your API key is 75[redacted]4d
- Within the next couple of hours, it will be activated and ready to use
- You can later create more API keys on your account page
- Please, always use your API key in each API call

Endpoint:

- Please, use the endpoint api.openweathermap.org for your API calls

Fig.3: if all goes well with registration, you'll get an email from openweathermap.org **with your API key (we've redacted ours so you can't steal it!). Copy this into the Arduino sketch at the OWM_API_KEY define between the quote marks. Keep your API key secure, as anyone that has it can use your allowance.**

the Arduino IDE provides EEPROM emulation by using a small amount of Flash storage.

Thus, these settings are retained during power-down and are loaded at power-up. Once set up, the screen usually displays complete information within around ten seconds of power being applied.

Mounting

If you simply wish to use the unit in a freestanding enclosure, then mounting is much the same as for the *Micromite LCD BackPack V3*, and you can use the lid designed for that project to mount it into a UB3 Jiffy box.

You may like to provide a DC input jack on flying leads to be mounted on the case, if the existing cable entry doesn't suit your application.

Like the Altronics Inventa Plates, we expect some people will install these into a wall cavity. This could be as simple as using the acrylic piece noted above as a bezel.

Another simple way to do this is to make a square cutout in a blank wall plate, as well as four round 3mm holes for the screws. The *D1 Mini BackPack* can then mount similarly to other BackPacks, using a screw in each corner to secure it.

You could use the blank PCB as a template for the holes; this may be easier than a populated PCB or the LCD with its protruding headers.

If you are mounting it to a wall which has mains wiring behind, consider adding a spacer block to keep it separate. This will also reduce the size of the hole which needs to be made in the wall.

Beyond the demo

Our software provides a useful function, but it really shows only a tiny fraction of what can be done with this hardware. Many other useful features can be added relatively easily.

With the popularity of the Arduino IDE and ESP8266, there are numerous examples of what can be done online. This includes tapping into online resources to display data, plus protocols to interact with other devices within your LAN, or even via a VPN.

Table 1 shows the D1 Mini's pin configuration, which should be very helpful if you plan to modify the code. Unlike AVR-based boards, many of the pins on the D1 Mini have individual characteristics, meaning they are not entirely interchangeable. Therefore, we chose carefully the pins used for the *D1 Mini LCD BackPack*.

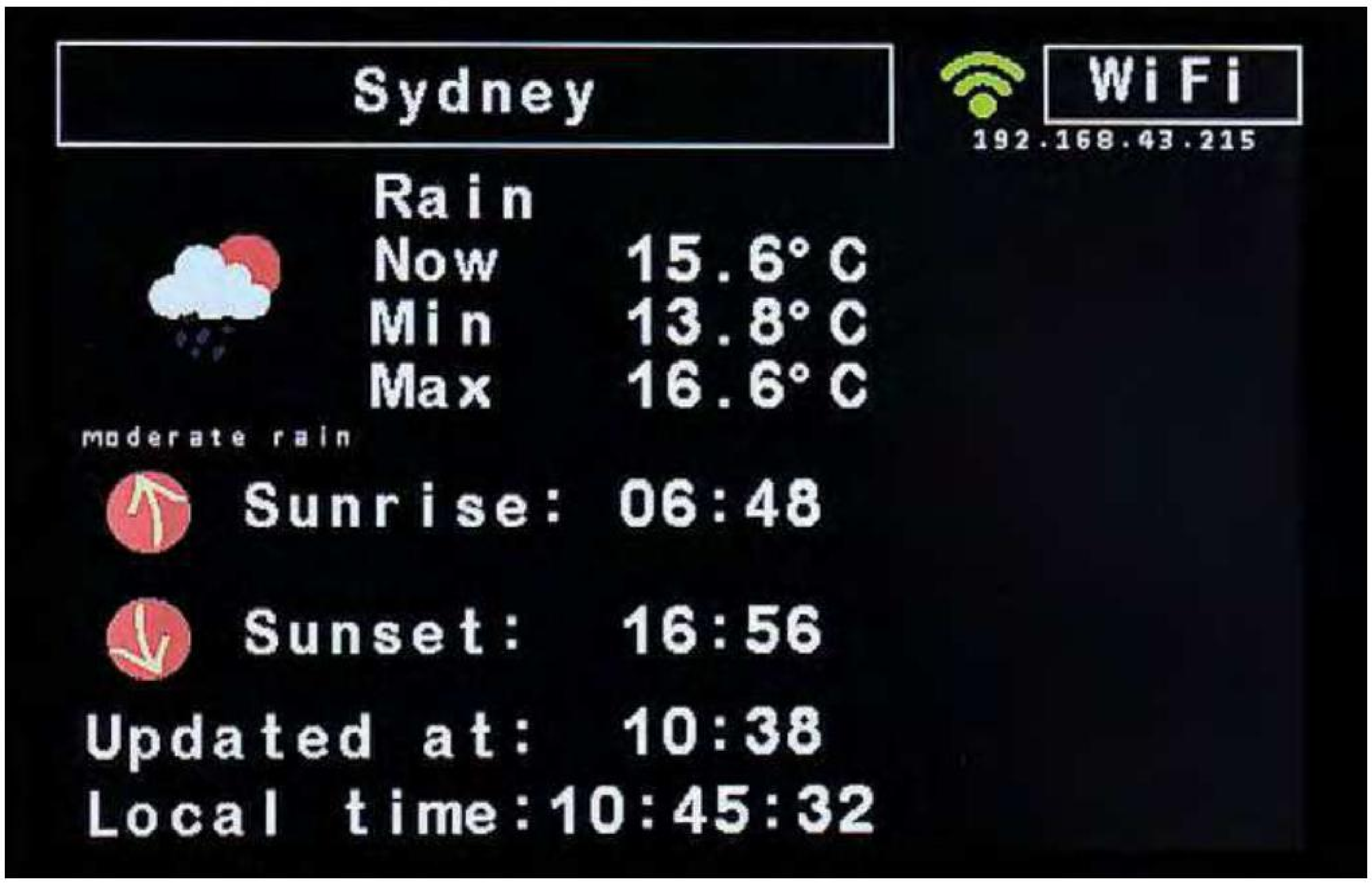
Over-the-air programming

One of the libraries within the Arduino ESP8266 board profile provides a very useful feature, especially if you plan to mount the unit in a wall permanently.

'Over The Air' (OTA) programming means that sketches can be uploaded to the unit via Wi-Fi. The sketch needs to have the OTA library included, so the first sketch upload must be done through the serial port, but as long as subsequent code uploads include the OTA library, OTA can continue to be used.

Some limitations exist; for example, the ESP8266 must have enough space to hold the currently running sketch alongside the new sketch. This effectively cuts the available sketch Flash space in half.

The mechanism means that the ESP8266 must be connected to the same Wi-Fi network as the user; if it has lost its Wi-Fi credentials, then OTA will not work.



Screen1: the main page of our demo application shows a swathe of information from OpenWeatherMap. We tried to use a PNG decoding library to display the icons, but it still had a fairly high dynamic memory requirement and did not work. So instead, the icons are stored in the Flash memory.

Being programmable over Wi-Fi also means that someone else with Wi-Fi access could reprogram the unit, although a basic password feature is provided. Still, it's a handy feature to have, especially if you need to test the unit in situ, or if it's difficult to connect a USB cable.

There are example sketches (under the ArduinoOTA heading) and more information can be found here: **https://bit.ly/pe-oct21-ota**

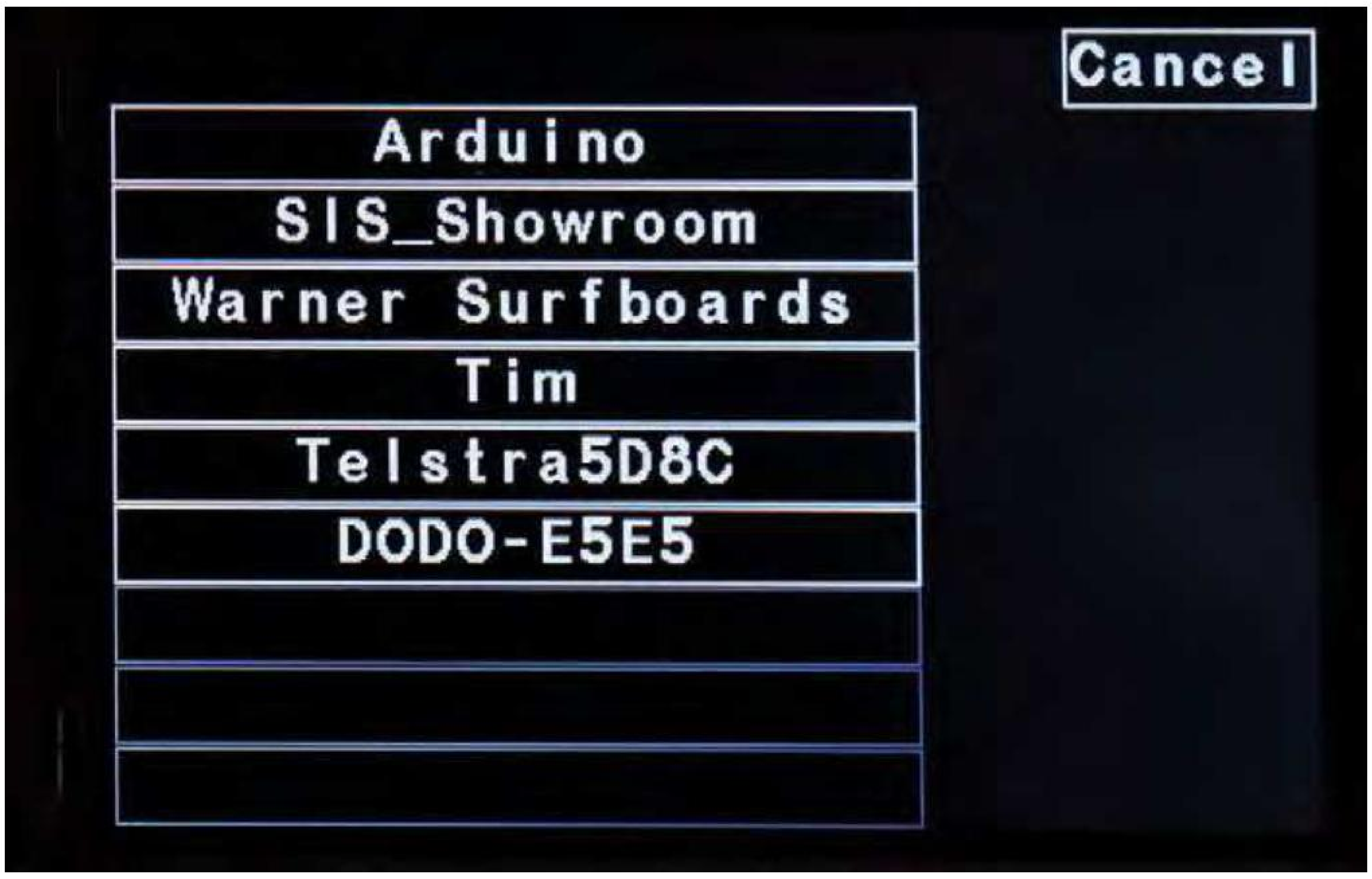
Summary

While the demonstration program shown here is quite useful in its own right, it's intended to be a starting point for other projects.

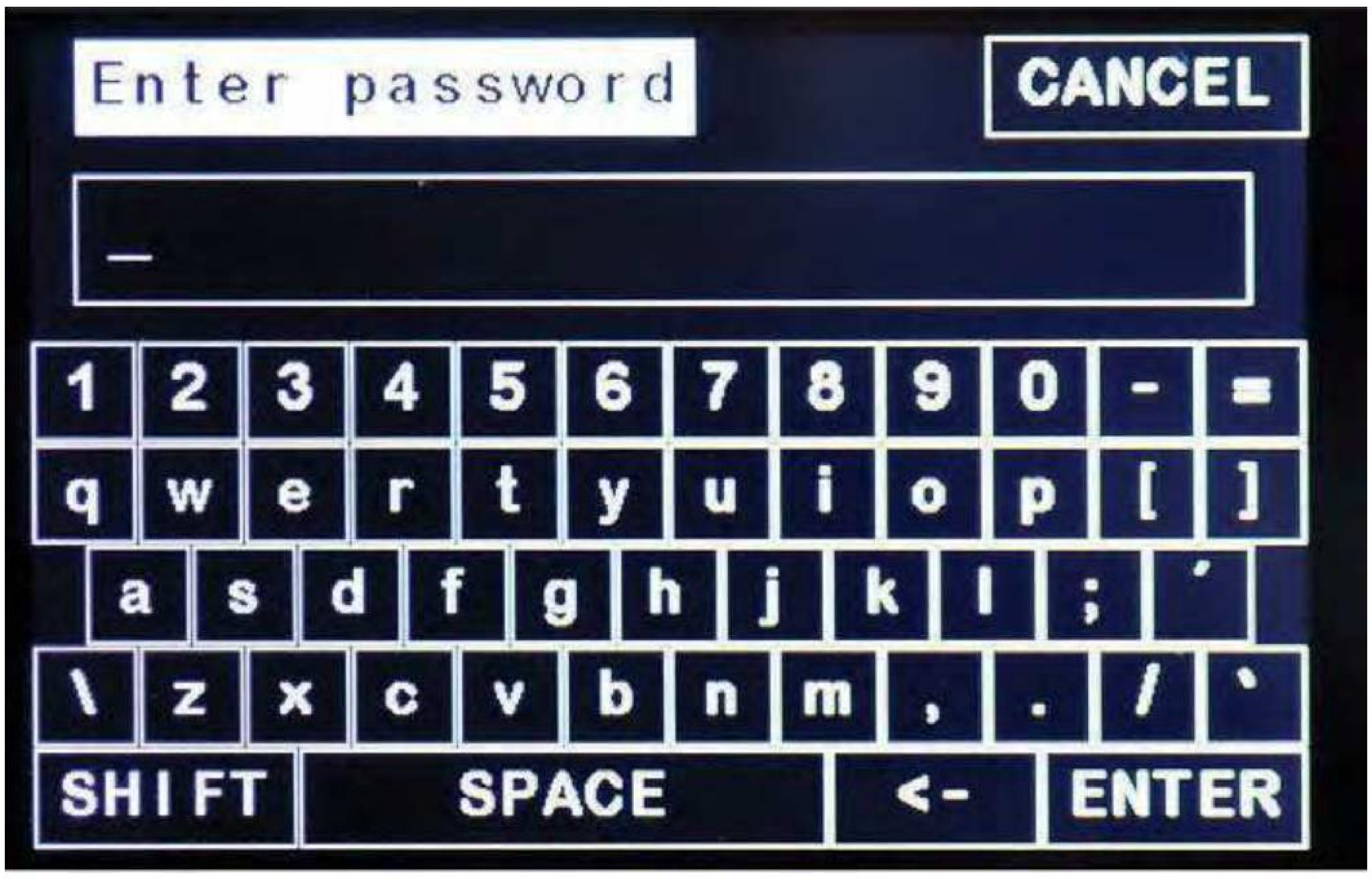
For example, many public transport operators make their data available. So it would be possible to display when the next bus is scheduled to leave your nearest stop, or even when it is coming down to the minute if realtime data is available.

D1 pin name	Pin number	Comments
D0	16	Initially high
D1	5	Default Arduino I^2C SCL
D2	4	Default Arduino I^2C SDA
D3	0	Has pull-up resistor to set the run mode at reset
D4	2	Has pull-up resistor to set the run mode at reset
D5	14	Hardware SPI SCK
D6	12	Hardware SPI MISO
D7	13	Hardware SPI MOSI
D8	15	Has pull-down resistor to set the run mode at reset
TX	1	Can be used as GPIO
RX	3	Can be used as GPIO
A0	–	Analogue input with a nominal full-scale value of 3.2V

Table 1: D1 Mini pin numbering



Screen2: the Wi-Fi setup page provides a similar interface to many 'smart' devices. Nearby networks are scanned and listed; the user simply has to enter the appropriate password.



Screen3: the benefits of a large touchscreen come to the fore on the password page. Here we can use the ample space to implement a full QWERTY keyboard that allows all ASCII characters to be entered. Most keys are at familiar locations; some have been moved for compactness. A similar screen is used to enter the weather location.

While many of these services require user registration, there is a freely available service for Melbourne tram information. It is documented at: **https://bit.ly/pe-oct21-tram**

This project also provides the perfect means of controlling other devices. An increasing number of home automation devices are becoming available, and many of them are suitable for integration in such a system.

Even in the case that this can't be done directly, there are alternative open-source firmwares which make this possible.

In particular, many of the ESP8266-based smart globes and switches can be modified by loading the open-source Tasmota firmware, go to: **https://tasmota.github.io/docs/**

This software and many others use the MQTT protocol; fortunately, there are numerous MQTT libraries for the ESP8266, so interfacing to this protocol is not hard.

Because it uses a publish/subscribe model, multiple devices can act on the same information.

There are also mobile phone applications which can be set up to provide an MQTT dashboard, for example, allowing MQTT data to be displayed or MQTT messages to be sent at the push of a button.

The big opportunity here is to automate actions based on the information that the D1 Mini can access. For example, turning on lights at sunset or turning off the heater if the outside temperature increases.

While the *D1 Mini BackPack* would only be a very small part of such a project, it is clearly a useful device in its own right.

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USB SuperCodec

Part 2

By Phil Prosser

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USB
SuperCodec
• 192kHz • 24-bit

Last month, we introduced our new *USB SuperCodec* sound card design, which boasts superb recording and playback performance. It isn't only useful for recording and playback though; with some inexpensive software, it can make a very advanced audio signal analysis system. Now it's time to describe the details of the circuitry behind its phenomenal performance.

We covered the basic operating principles of the *USB SuperCodec* in last month's introductory article, but we ran out of space to fit the full circuit details. As you will see from this article, that's mainly due to the number and size of the circuit diagrams.

Since the circuit of the *USB SuperCodec* is too large to fit across two pages, we have broken it up into five sections: the computer interface with galvanic isolation (Fig.12), local clock generation and asynchronous sampling rate conversion (Fig.13), the ADC section (Fig.14), the DAC section (Fig.15) and the power supply (Fig.16).

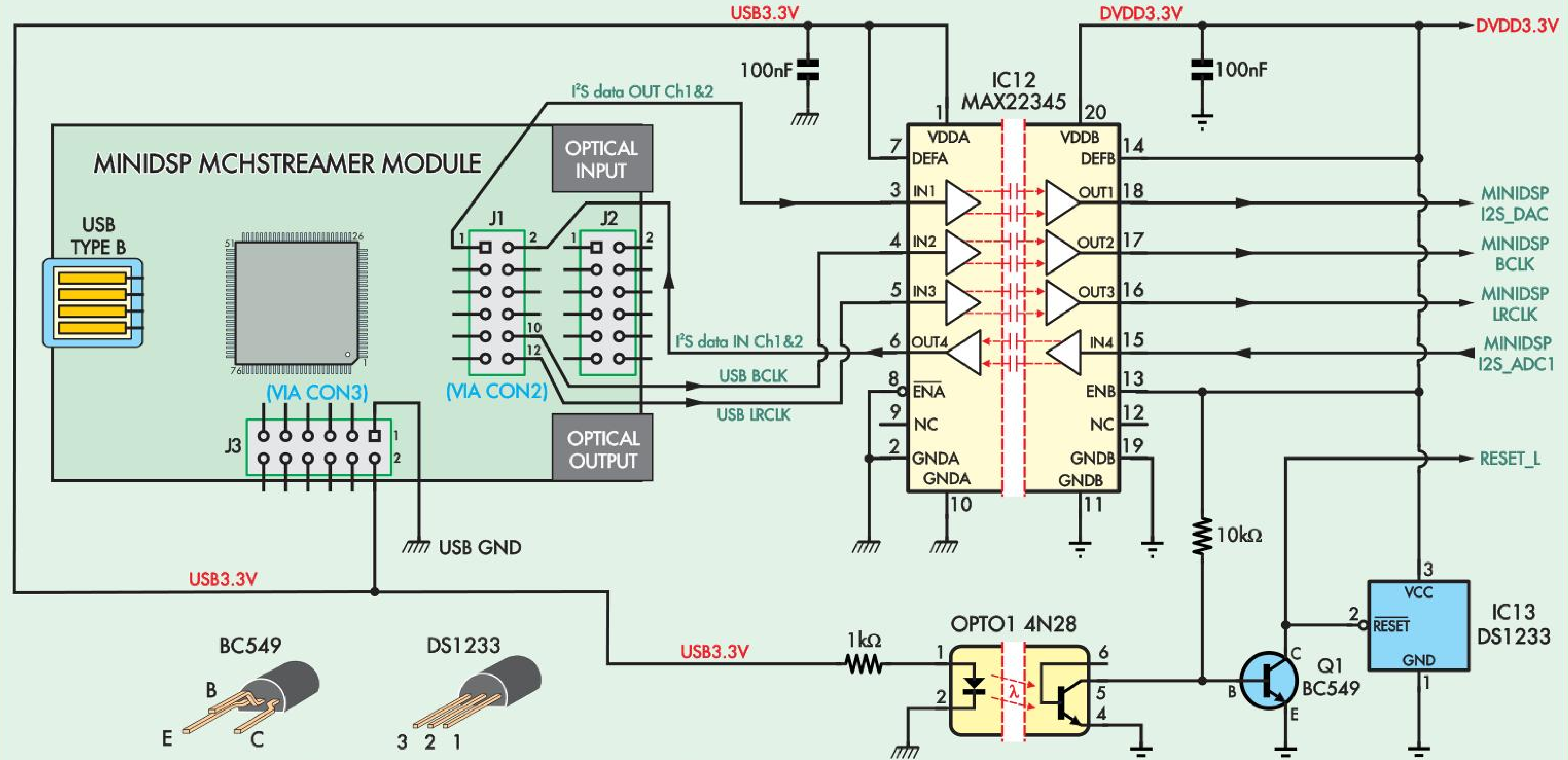
Galvanic isolation

The galvanic isolation is provided by IC12, a Maxim MAX22345 (see Fig.12). This is a fast, low-power, four-channel galvanic isolator chip. We are using the 200Mbps version as we wanted to be able to transfer clock signals at more than 12MHz (the bit clock [BCLK]) and 24MHz (the master clock [MCLK]).

The version that we are using provides three 'left to right' and one 'right to left' channels. This is ideal for isolating the I^{2}S output from the MCHStreamer.

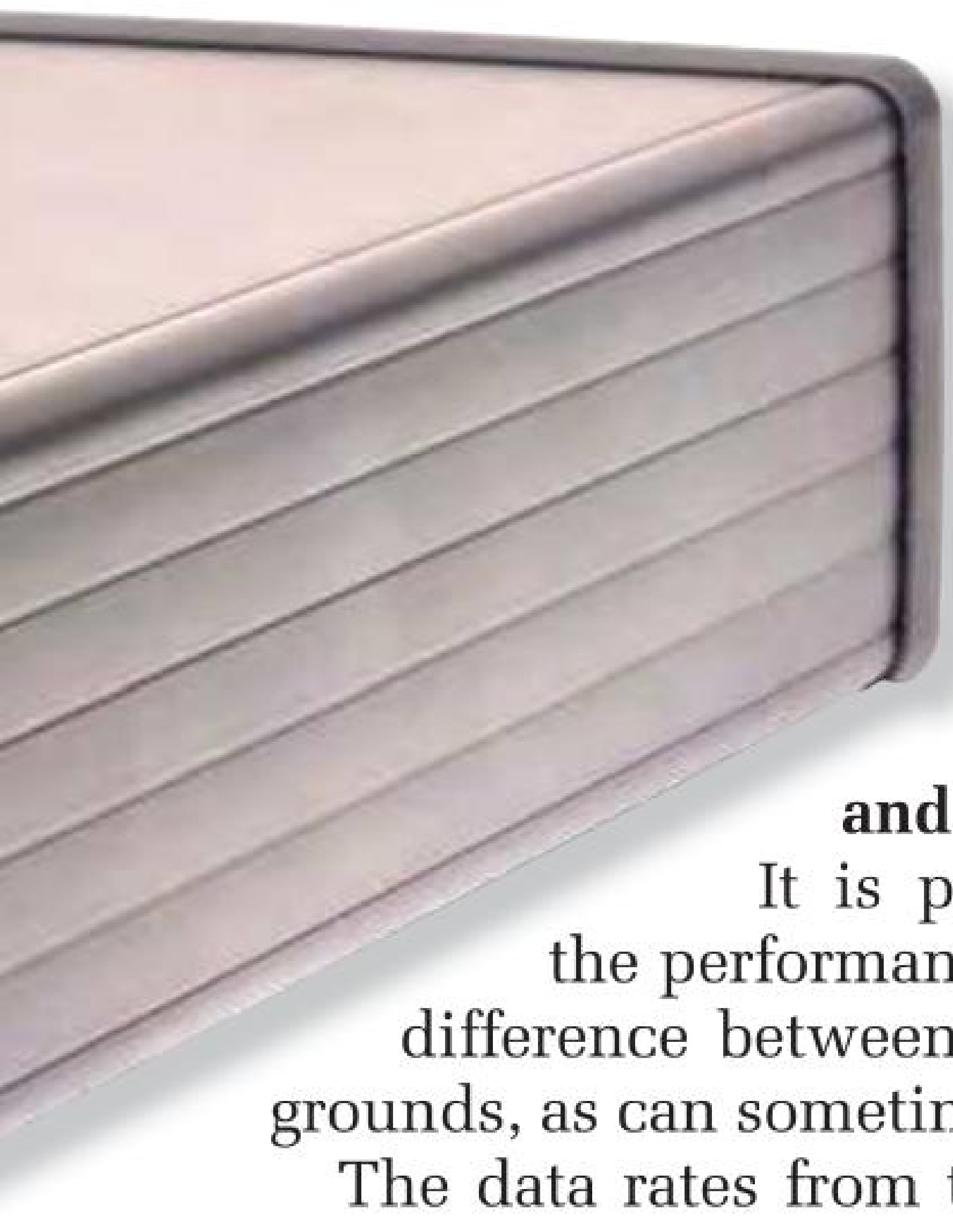
When we had the computer ground electrically connected to the USB sound card ground in a real-world system, we found it impossible to get rid of residual 50Hz-related noise and a bunch of 'spurs' in the noise floor. While these were low enough to be inaudible, putting the galvanic isolation into the system saw these drop significantly. Indeed, even allowing the USB earth to connect to the case of the *USB SuperCodec* increased the 50Hz hum by 10-20dB!

This chip is not that expensive, but the benefit of using it as part of a measurement system is huge.


USB3.3V
DVDD3.3V
100nF
100nF
IC12
MAX22345
I²S data OUT Ch1&2
MINIDSP MCHSTREAMER MODULE
OPTICAL INPUT
OPTICAL OUTPUT
USB TYPE B
J1
J2
J3
(VIA CON3)
(VIA CON2)
I²S data IN Ch1&2
USB BCLK
USB LRCLK
VDDA
DEFA
IN1
IN2
IN3
OUT4
ENA
NC
GNDA
VDDB
DEFB
OUT1
OUT2
OUT3
IN4
ENB
NC
GNDB
MINIDSP I2S_DAC
MINIDSP BCLK
MINIDSP LRCLK
MINIDSP I2S_ADC1
RESET_L
USB GND
10kΩ
1kΩ
OPTO1 4N28
λ
Q1 BC549
IC13 DS1233
VCC
RESET
GND
BC549
B
E
C
DS1233
3 2 1

SuperCodec (USB Sound Card) MiniDSP MCH Streamer and Galvanic Isolation Circuitry

Fig.12: this section of the full circuit connects the MCHStreamer to a MAX22345 high-speed isolator and a bog-standard 4N28 optocoupler. The latter releases the ADC and DAC reset lines 350ms after plugging in USB.



We must make it clear that while this device provides a high degree of isolation, we have not designed the circuit board to handle significant voltage differences between the two domains. Do not, in any circumstances, rely on this design to provide safety isolation between the PC and the sound interface! It is purely intended to improve the performance, and allow a few volts of difference between your computer and audio grounds, as can sometimes occur.

The data rates from the USB interface are quite high. The MCLK signal is at 24.576MHz for the 192kHz sampling rate, and the BCLK is half this, at 12.288MHz.

Design and layout of a board for reliable operation at 25MHz requires attention to detail, careful grounding and termination for long traces.

We have used series termination on the 25MHz clock signal, and managed to keep high-speed traces tidy and with a minimum of vias. They all run over a solid ground plane for their entire length. Where we have had to route across these signals, we made the aperture in the ground plane as small as possible.

We came close to using a four-layer PCB for this design, but by constraining the digital signals to a limited area, and with careful layout, we have avoided the cost this would incur.

In the final version of the design, we are using a local clock oscillator for the 24.576/25MHz clock, so while we can access the master clock from the MiniDSP MCHStreamer, it is not used, as we can do better with a local clock source. Hence, Fig.12 does not show any connection to the MCLK pin of the MCHStreamer module.

In case you're wondering how the MAX22345 works, isolators like this generally get the signal across the isolation barrier using either magnetic or capacitive coupling (high-speed optical isolators exist but are usually bulkier). Maxim does not explicitly state which, but it appears to be capacitive.

We're also using an ordinary old 4N28 optocoupler. This tells the audio side whether or not power being received from the computer.

If there is no power, the ADC and DAC are held in reset. Once there is 3.3V power from the USBStreamer, the ADC and DAC are taken out of reset after 350ms. The DS1233 provides this delay; the signals from the USB Streamer should have stabilised after 350ms. From a user's perspective, this means that when you plug the *USB SuperCodec* in, it looks after its own reset and 'just works'.

Local clock generation and ASRC

This section has been the subject of a lot of work. It would be possible to drive the ADC and DAC directly from the miniDSP MCHStreamer, as isolated by the MAX22345.

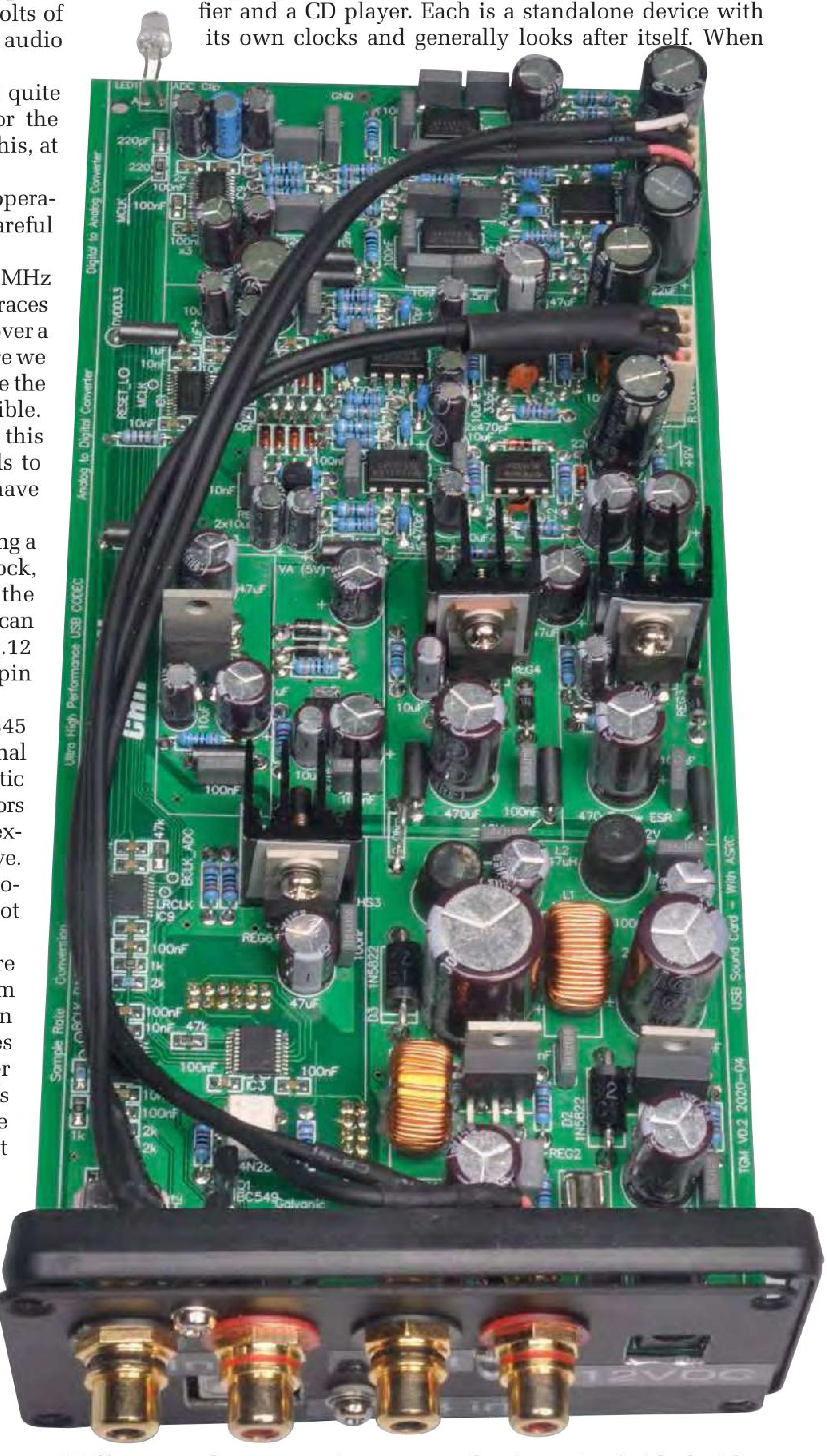
But what if the user wants to operate the card at 44.1kHz, 48kHz, 96kHz, 192kHz or some other rate? How do the ADC and DAC get set up for this?

The CS4398 and CS5381 chips both have mode pins that must be set depending on the sampling rate at which we want to operate.

In the prototype, we used jumpers to set the sampling rate for the ADC and DAC. We quickly decided that users will want to plug the card in and have it sort this out for itself. It would be possible to, say, use a microcontroller to sense the sampling rate and set the chips up accordingly. But there is a better way – using a device called an asynchronous sampling rate converter (ASRC).

ASRCs are found in professional recording studios and also consumer equipment which have digital-audio-to-digital-audio interfaces.

Imagine you have two digital audio devices, say an amplifier and a CD player. Each is a standalone device with its own clocks and generally looks after itself. When


Digital to Analog Converter
Analog to Digital Converter
Ultra High Performance USB CODEC
Sample Rate Conversion
USB Sound Card – With ASRC
TGM V0.2 2020-04
12VDC

We'll get onto the construction next month, after we've finished with the rather involved description. To whet your appetites, here's the completed PCB mounted on the input/output socket, shown life size.

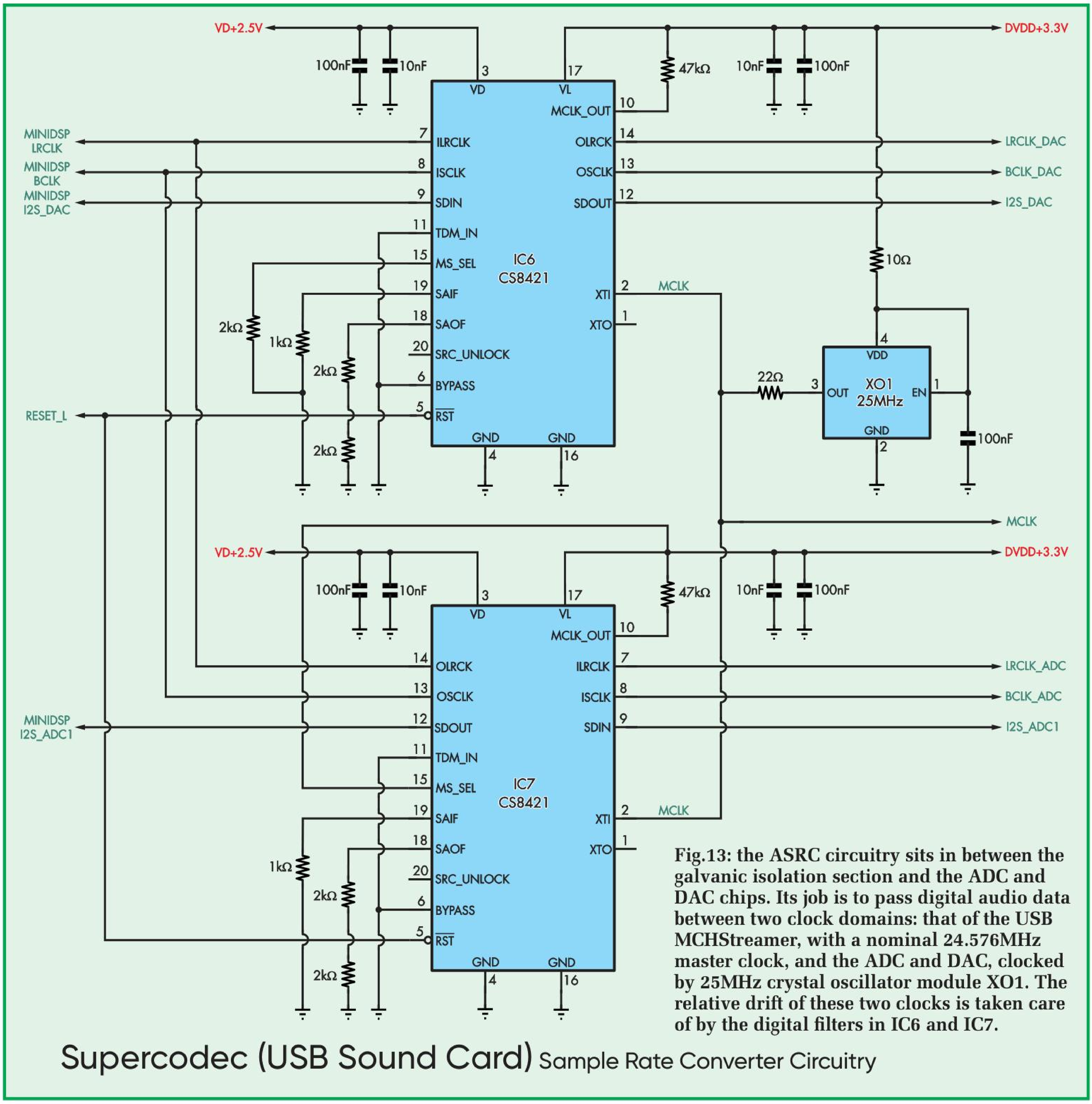

VD+2.5V
100nF
10nF
3
VD
17
VL
47kΩ
10nF
100nF
DVDD+3.3V
10
MCLK_OUT
MINIDSP LRCLK
MINIDSP BCLK
MINIDSP I2S_DAC
7
ILRCLK
8
ISCLK
9
SDIN
11
TDM_IN
15
MS_SEL
19
SAIF
18
SAOF
20
SRC_UNLOCK
6
BYPASS
5
RST
14
OLRCK
13
OSCLK
12
SDOUT
LRCLK_DAC
BCLK_DAC
I2S_DAC
IC6
CS8421
10Ω
2
MCLK
XTI
1
XTO
2kΩ
1kΩ
2kΩ
2kΩ
RESET_L
22Ω
3
OUT
XO1
25MHz
EN
1
4
VDD
GND
2
100nF
GND
4
GND
16
MCLK
VD+2.5V
DVDD+3.3V
IC7
CS8421
OLRCK
OSCLK
SDOUT
ILRCLK
ISCLK
SDIN
LRCLK_ADC
BCLK_ADC
I2S_ADC1
MINIDSP I2S_ADC1

Fig.13: the ASRC circuitry sits in between the galvanic isolation section and the ADC and DAC chips. Its job is to pass digital audio data between two clock domains: that of the USB MCHStreamer, with a nominal 24.576MHz master clock, and the ADC and DAC, clocked by 25MHz crystal oscillator module XO1. The relative drift of these two clocks is taken care of by the digital filters in IC6 and IC7.

Supercodec (USB Sound Card) Sample Rate Converter Circuitry

you plug these together, if you want to have the CD player provide digital data to the amplifier, what happens if (as is inevitable), the CD player's clock is just slightly different in frequency to the clock in the amplifier?

Eventually, the CD player will provide either too much or too little data to the amplifier. In serious situations (eg, professional mixing rigs), you can have a master clock distribution system. But most devices don't have provision for that. Alternatively, you can use an ASRC.

Instead of locking the clocks of different chips together, the ASRC flips the problem on its head. It allows our ADC and DAC to have their own clocks, and does a bunch of maths to pass the correct digital values to and from the computer at whatever sampling rate it happens to be running at.

This involves the ASRC monitoring the different sampling rates, then implementing digital filters to deliver the exact digital value needed at every sample interval.

The upshot of this is that we can use a local 25MHz clock source to drive both the ADC and DAC. The clock we have chosen is good without getting silly. Its typical RMS jitter is less than 1ps (one million millionth of a second!). You could go for a better unit, but our analysis suggests that the difference would be essentially unmeasurable. Indeed using a 'better' clock is a tweak that some serious audiophiles do.

We have used a sample rate converter in each of the ADC and DAC lines, as we need to perform this translation for both recording and playback.

The devices we're using are both Cirrus Logic CS8421s. If you are worried about what these things may do to the sound, fear not. These are rated for 175dB dynamic range and –140dB (0.00001%) THD+N!

So the impact of these devices is so low that it is not at all detectable, let alone audible. (We have donned our asbestos underwear as we await the flame throwers of the anti-ASRC audiophile crowd!)

The actual implementation of these chips is not complex, as shown in Fig.13. The digital audio signals go into pins 7, 8 and 9 at one particular sampling rate and emerge from pins 12, 13 and 14 at a different rate, to match up with the clock signal applied to pins 2.

Using an ASRC has a couple of implications on how the ADC and DAC are set up and driven.

First, we must provide a low-noise clock. This is from XO1, a 25MHz clock oscillator module.

Second, we need the local left/right clock (ie, sampling rate) at a higher rate than the 192kHz that the MiniDSP USBStreamer uses, to ensure no degradation of the digital signal. 25MHz divided by 32 (bits each in the L and R samples) divided by 2 then 2 again is 195.3125kHz. So that suits us fine.

We need to set the ASRC for the CS4398 DAC as a master output so that it generates the 195.3125kHz left/right clock (LRCK) and control signals for this ADC on its output – ie, the ASRC drives the DAC at this rate at all times.

We need the ASRC for the CS5381 ADC as a master input so that it generates the 195.3152kHz clock and control signals for the MCHStreamer on its input.

Pin 6 (BYPASS) allow the ASRC action to be disabled, but since we always want it active, we have tied this to GND. Similarly, we are not using the Time Domain Multiplexing (multi-channel) feature, so pins 11 are tied low.

The MS_SEL pin of IC6 is pulled down via a 2kΩ resistor, which sets the device to slave mode on its input side (clocks are inputs), and master mode on its output side (clocks are outputs). The 1kΩ resistor from pin 19 (SAIF) to ground sets the inputs of both devices to 32-bit I^{2}S mode; one of six different digital audio protocols this chip supports. This matches the data format from the MCHStreamer.

Similarly, the 4kΩ total resistance from pins 18 (SAOF) to ground sets the output side to I^{2}S mode with 24-bit data, to suit our ADC and DAC chips. This is one of 16 possible formats the chip supports.

Once set up as above, this forms a neat interface between parts of a system that may have differing clocks. Is there a downside? They are not cheap devices, but we think they're worth it for the flexibility they provide.

Analogue-to-digital conversion

We're using the CS5381-KZZ chip. Cirrus Logic make two similar devices, the CS5361 and CS5381. They are pin-compatible, but the CS5381 has better distortion performance.

We have specified the better of the two. You could drop in the CS5361 instead, and will lose a bit of performance on the input channels.

The circuitry surrounding this chip, shown in Fig.14, is close to what is recommended by the Cirrus Logic application note. However, we have gone to extra lengths to ensure very symmetrical drive of the input, and to make sure that the sound card has a high-impedance input. Ferrite beads FB3 and FB4, with the following 100pF capacitors to ground, form RF filters at the inputs.

Bipolar electrolytic capacitors block DC voltages, with a –3dB cutoff well below 1Hz. Schottky diodes D5, D10, D15 and D16 protect the op amp inputs against spikes and excess voltage. In normal operation, these do not affect the signal.

IC2a/IC4a operate as unity-gain buffers. They provide a low-impedance drive for the following two stages without affecting the input. IC2b/IC4b operate as inverters. We have used 1.2kΩ feedback resistors, as low as practical, to keep noise down while allowing the operational amplifier to drive the following stage without any concern of increasing distortion by overloading the output.

SOURCING THE COMPONENTS

Some of the components for this project are rather specialised and might be difficult to track down.

To assist you in this endeavour, we have produced a spreadsheet which gives catalogue codes for each part needed, from six different sources:

• Altronics • Jaycar • Digi-Key • Mouser • element14 • RS

You'll find this spreadsheet at: **https://bit.ly/pe-oct21-codec**

We could have gone a touch lower in resistance, but feel this is a good compromise on performance and power use.

IC3a/IC5a and IC3b/IC5b drive the differential inputs of the ADC, and all four stages are configured in a very similar manner. There are a couple of things going on here.

The non-inverting inputs are held at a 2.5V bias via 10kΩ resistors from IC1's VQ (quiescent voltage) pin, pin 22. These resistors have 10nF local bypass capacitors to ensure the op amps see a very low source impedance.

The inverting inputs of these op amps are driven by the in-phase and inverted signals from the previous stage, which are capacitively-coupled to support the DC offset. You might be concerned that the input signal could affect the 2.5V, but these signals are balanced, so their effects on the reference voltage essentially cancel out.

The 470pF feedback capacitors form low-pass filters in combination with the 680Ω and 91Ω resistors. This has a cutoff way above the audio band, at around 500kHz, to ensure stability and get rid of any RF noise which makes it past the input filter.

Note that at audio frequencies, these four stages form unity-gain buffers. The fact that the output is taken from the junction of the resistors reduces transient loading on the operational amplifier.

Some low-pass filtering is provided by the combination of these resistors and the 2.7nF capacitors across the pairs of differential ADC input pins. These capacitors are mounted very close to the input pins. Our testing showed that these capacitors are critical to the performance of the ADC.

Do not use any old capacitor. Do not use an 'audiophile' capacitor. *Do* use a ceramic NP0 or C0G type capacitor, surface mounting, of known provenance. We built a prototype with a film capacitor here, and the distortion went up by a factor of ten. We also tried silver mica caps, and they were no better.

Clearly, it isn't just the linearity of this capacitor that is critical; the oversampling ADC draws pulses of current from these caps at a high frequency, so we need caps with a low ESR at several megahertz, as well as linearity. Only NP0/C0G ceramics provide both.

The ADC input pins have BAT85 diodes to each rail for protection. Reviewing the data sheet, it seems that the ADC should survive the maximum output current of a NE5532, but it might not survive the maximum output current of an LM4562. We suspect that some people might try different op amps – and since IC1 costs around £27.50 (!) – it's worthwhile providing protection.

The VA analogue supply to IC1 is nominally 5V, and we have a local low-dropout linear regulator (REG5) to provide a 3.3V digital logic supply rail for IC1. We have done this locally as it draws little current and made the layout so much easier.

Pin 15 of the ADC provides an overflow indication. This drives the LED on the front of the unit. Should this flash during operation, you are driving the ADC into clipping, and need to lower the input level.

Generally, you should be running the input substantially lower than this. The noise and distortion are optimal at a decibel or so below clipping, and even if you run this 10dB lower, the impact on performance will be minimal.

The ADC pins at upper right are tied either to VL or GND to set it up in 'hardware mode' (ie, not being controlled by a microcontroller), with the correct audio format selected. The digitised audio signals appear at pin 9 of IC1 and goes onto ASRC IC7, as shown in Fig.13. That same ASRC chip and XO1 provide the clock signals at pins 3, 4 and 5 of IC1.

Digital-to-analogue conversion

The CS4398 DAC is configured in a fairly conventional manner – see Fig.15. Discussing the right channel, IC9's differential outputs drive two low-pass filters formed by IC8a and IC8b. The filter on each pin is set up to present the same load to the two outputs. The impedances have been kept low to minimise noise. This filter is the same as used in the *DSP Crossover* (*PE*, January – March 2020) and limits the output of supersonic signals.

We have specified C0G ceramic capacitors (or NP0; same thing) where ceramic types are used. This is very important as other dielectrics will introduce more distortion.

For the 1.5nF, 10nF and 22nF capacitors we used MKT capacitors. The self-resonance of low-value MKTs is typically in the 10MHz region, so the filter behaved well and provided excellent performance. They are easier to obtain than NP0/C0G ceramics with those same values, so you might as well stick with the MKTs. But if you use very high-speed op amps in place of the NE5532s, things could change.

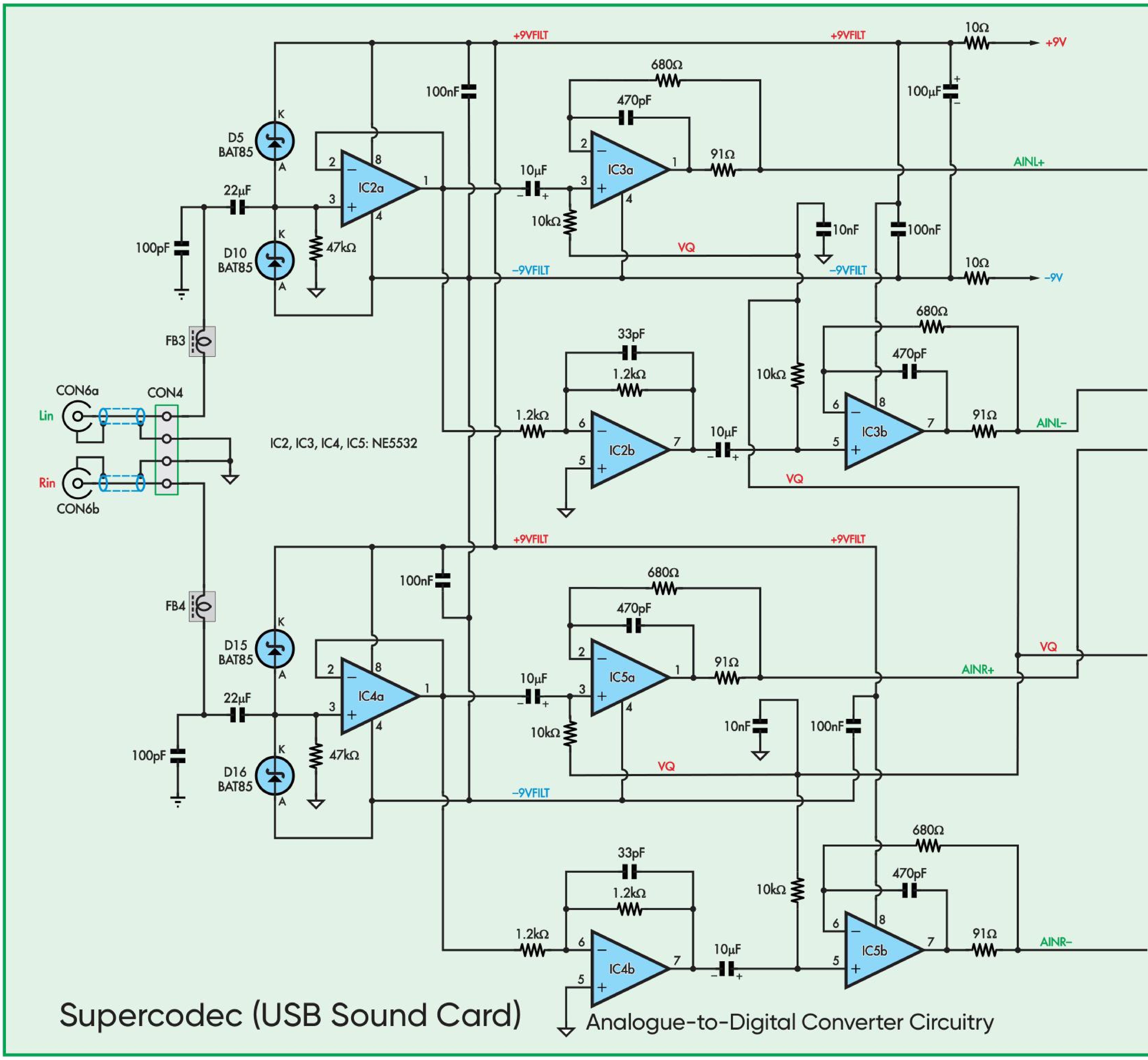
IC10b forms a differential-to-single-ended signal converter. The 1.2kΩ resistor values are low enough to minimise noise while not overloading the op amp, and leave headroom for it to drive a load. The 470pF capacitors in this stage form the final stage of the low-pass filter.

The DC output level of the DAC is 2.5V. This runs through the filters formed by IC8a and IC8b. Rather than AC-coupling the signal to the differential to single-ended converter, we have used the converter to remove the bulk of the DC offset itself. The AC-coupling capacitor at its output removes any residual DC – though in our prototype, this was a very low level.

The power supply

The power supply, shown in Fig.16, may look over the top. This design makes no apology for taking power supplies and grounding to something of an extreme as we aim to deliver solid ADC and DAC performance, at the parts-per-million level. In particular, any noise on the +5VA rail is a very bad thing, and we want the +5VL and ±9V rails to be clean of noise and clocking artefacts.

The first version of this unit used a toroidal transformer mounted on the opposite side of the case from the sensitive analogue parts. It even included a copper shorting ring to reduce radi-


Supercodec (USB Sound Card)
Analogue-to-Digital Converter Circuitry
IC2, IC3, IC4, IC5: NE5532
CON6a
CON6b
CON4
Lin
Rin
FB3
FB4
D5 BAT85
D10 BAT85
D15 BAT85
D16 BAT85
K
A
100pF
22µF
47kΩ
100nF
10µF
10kΩ
680Ω
470pF
91Ω
33pF
1.2kΩ
10nF
100µF
10Ω
IC2a
IC2b
IC3a
IC3b
IC4a
IC4b
IC5a
IC5b
+9VFILT
–9VFILT
VQ
+9V
–9V
AINL+
AINL–
AINR+
AINR–

ated noise. Even so, we could still see the 50Hz leaking into the plots down around the –110 to –130dB levels.

So we changed it to run off a single +12V DC plugpack. It uses two LM2575 buck regulators (REG1 and REG2) to generate a +6.5V DC rail and –12V DC rail. This choice might raise a few eyebrows as switchmode converters are not famous for low levels of radiation.

And you may wonder how the same chip is used to generate both positive and negative rails.

Let's start with that negative rail. In essence, we are turning REG2 on its head; its positive output connects to GND (after the LC filter), while its GND pin is actually 'floating' on the negative rail! It may seem strange, but if you analyse the circuit carefully, you will see that this will work.

But there are a few things you need to be aware of when using a buck regulator this way. On startup, it tends to draw a lot of current for a short period. The Texas Instruments data sheet warns of this, and they were right to! The peak startup current is about 2A, so be sure to use the recommended plugpack, or check that yours works OK.

There is also an LM2576, which is a beefier version of the LM2575. This draws closer to 4.5A on startup. It works, but watch that startup current.

So how does this work? Here's a brief explanation: REG2 'tries' to keep the feedback voltage at pin 4 about 1.25V above its ground pin, pin 3. As the –12V rail is initially at 0V, so is pin 4, so the output switches on hard. This means that current can pass from the 12V input, through inductor L3 and to ground.

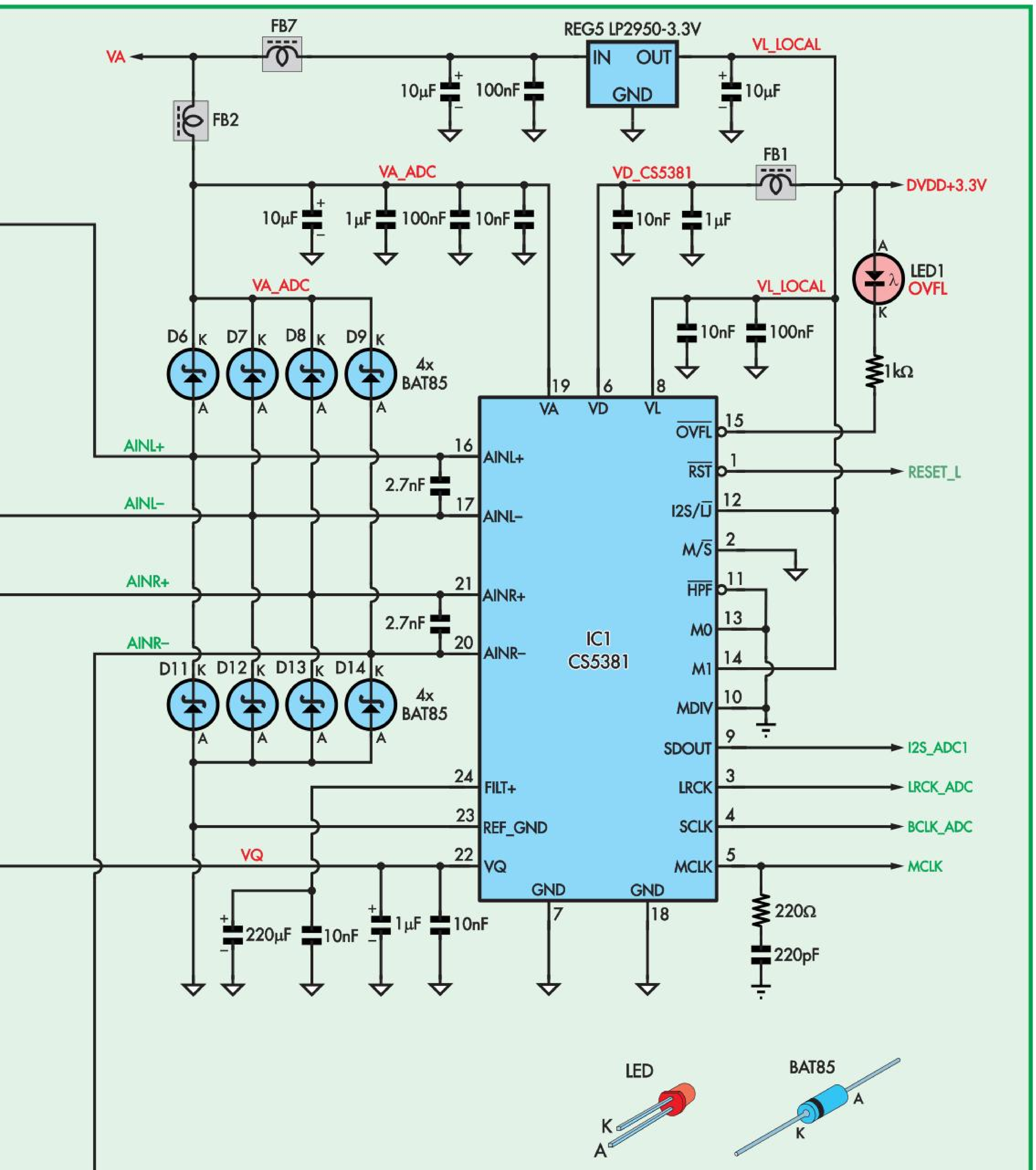

FB7
REG5 LP2950-3.3V
IN
OUT
GND
VL_LOCAL
VA
10µF
100nF
10µF
FB2
FB1
VA_ADC
VD_CS5381
DVDD+3.3V
10µF
1µF
100nF
10nF
10nF
1µF
A
LED1
OVFL
λ
K
VA_ADC
VL_LOCAL
10nF
100nF
D6
D7
D8
D9
K
4x
BAT85
A
1kΩ
19
6
8
VA
VD
VL
15
OVFL
AINL+
16
AINL+
1
RST
RESET_L
2.7nF
AINL–
17
AINL–
12
I2S/LJ
2
M/S
AINR+
21
AINR+
11
HPF
13
M0
2.7nF
IC1
CS5381
AINR–
20
AINR–
14
M1
D11
D12
D13
D14
4x
BAT85
10
MDIV
9
SDOUT
I2S_ADC1
24
FILT+
3
LRCK
LRCK_ADC
23
REF_GND
4
SCLK
BCLK_ADC
VQ
22
VQ
5
MCLK
MCLK
GND
GND
7
18
220Ω
220µF
10nF
1µF
10nF
220pF
LED
K
A
BAT85
A
K

Fig.14: the stereo analogue audio signals applied to RCA sockets CON6a and CON6b are buffered and pass through a series of RF filters before being converted to balanced (differential) signals, which are then fed to the pairs of ADC inputs at pins 16/17 and 20/21 of IC1. The 2.7nF filter capacitors are critical to getting good results, while numerous schottky diodes protect the various ICs from signal overload.

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Tweaking the SuperCodec's performance

Phil Prosser delivered a prototype to us with excellent performance. However, on measuring its performance, we detected an anomaly. The DAC THD+N figure increased for test frequencies below 200Hz, rising from 0.00054% at 1kHz to around 0.00085% at 20Hz.

This was not what we expected, as performance usually improves as the test signal frequency drops.

At first, we suspected that the 22µF bipolar output coupling capacitors could be the culprits, as rising distortion with decreasing frequency is a signature of coupling-capacitor-induced distortion. However, replacing these with 100µF high-quality devices (which you may have noticed in our photographs) failed to yield any improvement.

This led us to suspect that the low-frequency signal was modulating a voltage rail, so we turned our attention to the capacitors surrounding the CS4398 DAC, IC9.

The most critical capacitors are the electrolytic filter capacitor on pin 26, VQ, which stabilises the half-supply rail (quiescent output voltage, hence VQ); the 33µF filter capacitor at pin 17 (VREF), which also helps to smooth the VA (analogue supply voltage) 5V rail that it's connected to; and the electrolytic capacitor at pin 15 (FILT+). The capacitor from pin 26 to ground was originally 3.3µF. After soldering a 47µF capacitor across it, we re-tested the unit and found two things.

One, it took a lot longer to reach normal operating conditions (presumably the larger capacitor takes longer to charge). And two, while the THD+N figures did drop around 25% at lower frequencies (and a bit across the board), there was still a rise in distortion below 200Hz.

Adding a 470µF capacitor from pin 17 (VREF) to ground did nothing, indicating that this rail was sufficiently noise-free. But moving that capacitor to go from pin 15 (FILT+) to ground, which originally had a 100µF in parallel with the 100nF, totally eliminated the rise in distortion at lower frequencies and also slightly lowered distortion across the board.

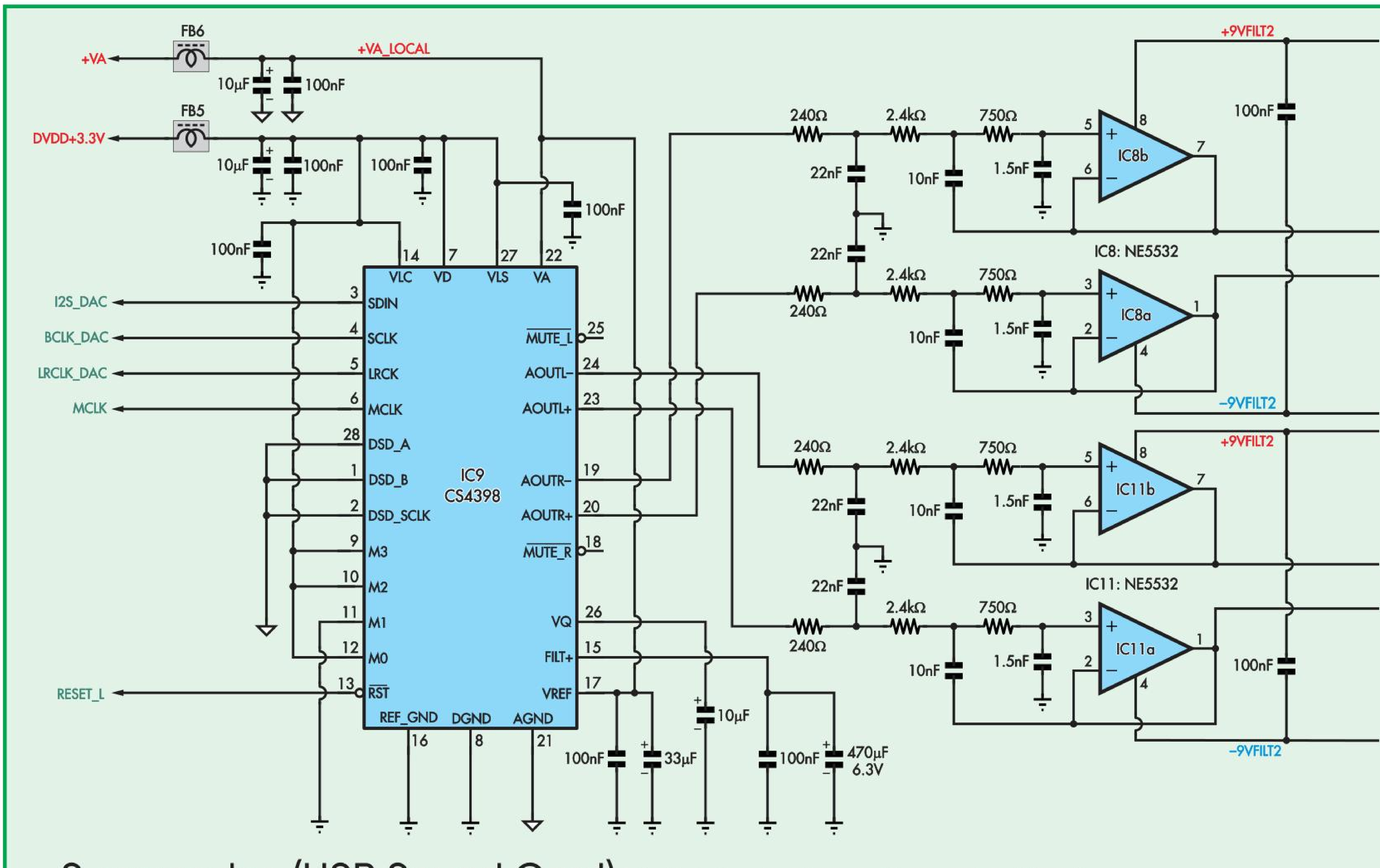
So we decided to compromise with the VQ filter capacitor at 10µF; higher than the original 3.3µF for improved overall performance, but not so high that the unit takes ages to stabilise when powered on.

And we definitely upgraded the 100µF capacitor at the FILT+ pin to a high-quality 470µF unit, which just fits, as this was the 'cherry on top' in terms of obtaining the ultimate performance.

The regulator switches its output in pulses at about 50kHz. When it switches off, the inductor's magnetic field causes current to continue to flow. This can no longer come from the LM2575, so the voltage at pin 2 drops and the current flows from the negative pin of the output capacitor, through D3. As a result, the voltage across the output capacitor increases, meaning its negative end gets more negative.

This cycle continues, with the capacitor charging further, resulting in the ground pin falling negative relative to the output. As the voltage across the feedback divider is increasing, the voltage at feedback pin 4 relative to pin 3 also increases. Eventually, the capacitor is charged to 12V, and the ground pin is now 12V below the feedback pin. Pin 4 is then at around –10.75V, ie, 1.25V above pin 3.

The regulator then operates normally, varying its mark to space ratio to keep this voltage as required. The regulator is essentially driving a short-circuit at startup, hence the fairly impressive but brief initial current demand.


FB6
+VA
+VA_LOCAL
10µF
100nF
FB5
DVDD+3.3V
10µF
100nF
100nF
100nF
100nF
14
7
27
22
VLC
VD
VLS
VA
I2S_DAC
BCLK_DAC
LRCLK_DAC
MCLK
3 SDIN
4 SCLK
5 LRCK
6 MCLK
28 DSD_A
1 DSD_B
2 DSD_SCLK
9 M3
10 M2
11 M1
12 M0
13 RST
RESET_L
IC9
CS4398
MUTE_L 25
AOUTL– 24
AOUTL+ 23
AOUTR– 19
AOUTR+ 20
MUTE_R 18
VQ 26
FILT+ 15
VREF 17
REF_GND
DGND
AGND
16
8
21
100nF
33µF
10µF
100nF
470µF
6.3V
240Ω
2.4kΩ
750Ω
22nF
10nF
1.5nF
IC8b
IC8a
IC8: NE5532
IC11b
IC11a
IC11: NE5532
+9VFILT2
–9VFILT2
100nF

Supercodec (USB Sound Card) Digital-to-Analogue Converter Circuitry

Still using the NE5532 – really?

We have specified NE5532 op amps for this project. This may be a point of contention with some readers.

We built eight of the DAC modules as used in the DSP Active Crossover, allowing a comparison of NE5532 and LM4562 devices, and were unable to conclusively measure one as better than the other. We expect that we were measuring the actual ADC and DAC performance. Given that the LM4562 costs more than the NE5532 (and consumes more power) there seemed to be no good reason to use them.

We have also used LM833 op amps; they work too, but not as well; they can't drive as low impedances as NE5532s, so require more of a distortion/noise tradeoff.

If you have a favourite op amp that you want to use, we recommend you install high quality machined sockets, as desoldering op amps from a double-sided PCB generally kills the op amp, and may damage the PCB. (Suitable sockets are the Altronics P0530 or similar). Things you would need to check if you do this include oscillation, ringing and leakage of high-frequency products from the DAC to the output.

We also suspect that you will, in the best case, get equivalent performance, and quite possibly worse. If you want to get the rated performance, it's best to stick with the devices that we tested!

To keep radiated noise from the switchmode supplies low, we have been rather careful with the layout, making sure current loops are small.

We have also used low-ESR capacitors throughout, as well as oversized toroidal inductors. This contains the magnetic field inside the inductors and avoids saturation, which would lead to increased radiation.

The switchmode supplies are also located as far from the low-level analogue electronics as we can manage. On our test plots, there is a tiny bit of noise visible around the 50kHz operating frequency, but it's so low that it doesn't matter. Also, that's above the range of our hearing, a fact that is no coincidence.

We used a large output capacitor of 2200µF to minimise noise. Then we added a 47µH/100µF LC low-pass filter to reduce noise at the output further.

At this point, the ripple on the supply rail is only a few millivolts.

The +6.5V supply is provided by a conventional implementation of a buck regulator, using REG1. Again, we have put in a 2200µF filter capacitor and 47µH/100µF post-regulator filter. This also uses low-ESR capacitors.

Why 6.5V? One problem you find with high-speed logic is that it can draw a fair current from low-voltage rails. We do not want to use a linear regulator to generate a 2.5V or 3.3V rail that might have to deliver 100-200mA. We would need to dissipate 1.7W: (12V – 3.3V) ×0.2A. This is possible, but is a real nuisance to dissipate in a small enclosure.

So instead, we are using switchmode regulators to generate +6.5V and –12V rails, and then feeding these into four linear regulators to produce very clean +5V, +3.3V, +2.5V, +9V and –9V supplies for the ICs. The input of each linear regulator is fed through a ferrite bead, to minimise the chance of any RF type signals passing through the regulator.

The +12V and –12V 'noisy' rails are regulated to +9V and –9V using LM317 and LM337 adjustable regulators. These have especially good ripple and noise rejection. The ±9V rails power the op amps for the ADC and DAC sections. Note that there is a further RC filter in the ADC and DAC domains, formed by 10Ω resistors and 47µF capacitors, to ensure isolation between the ADC and DAC supply rails.

A low-dropout AZ1117H regulator is used to generate the +5V VA rail. This is a low-noise rail, and if you analyse the PCB, you will find that it is routed away from the digital section. The DVDD +3.3V and VD +2.5V rails are for digital purposes, and use ordinary LM317 devices.

PCB layout trick

We'll be presenting the PCB design next month, along with the PCB assembly, testing and wiring instructions. But there are a few performance-related things to consider about the PCB, which we'll briefly mention before signing off.

With the power supply at the bottom, all the digital signals and power supplies run up the left-hand side of the board, and the low noise and analogue signals up the right-hand side. This is

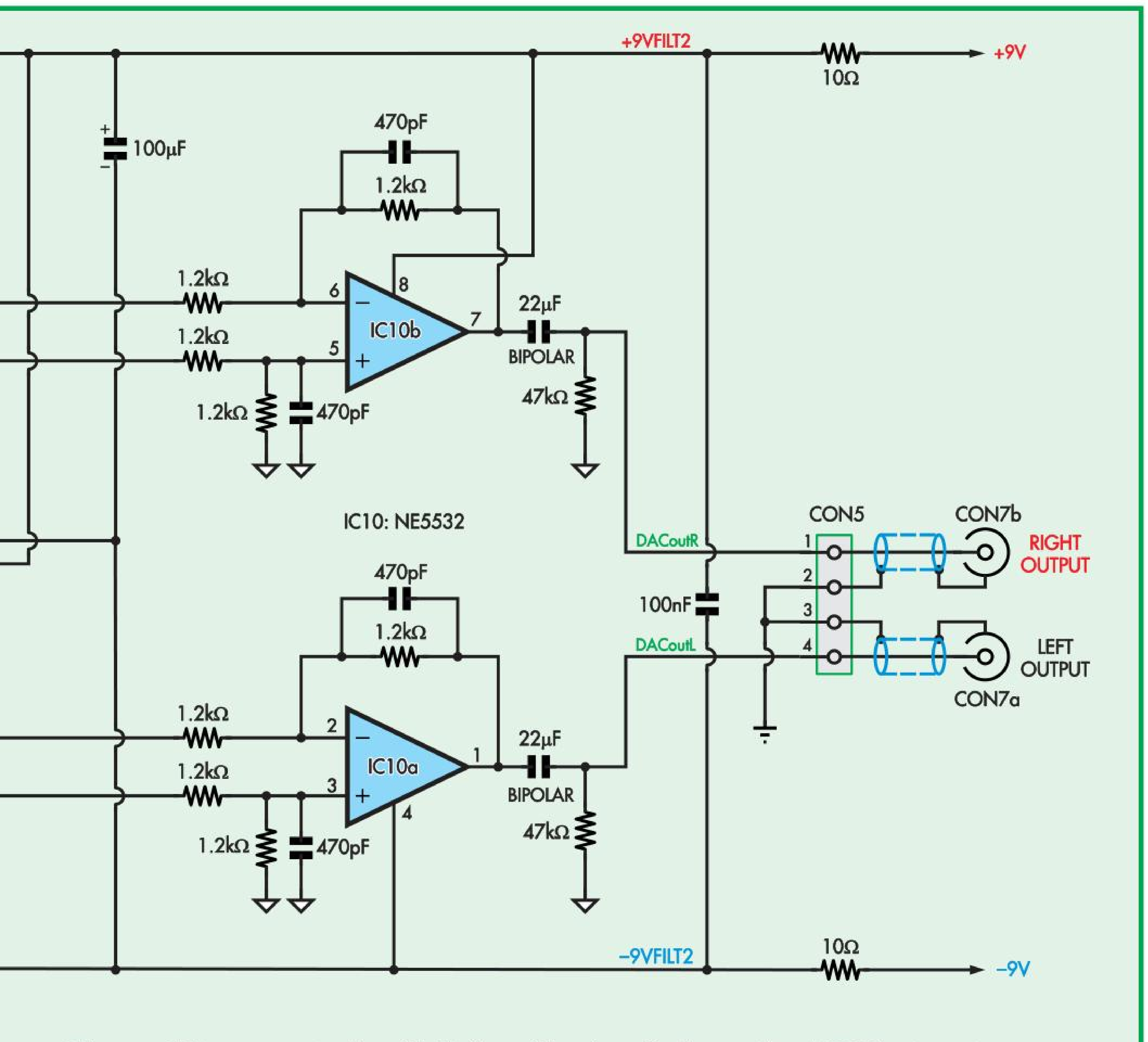


Fig.15: IC9 converts the digital audio signals from the ASRC stage to balanced analogue outputs at pin pairs 19/20 and 23/24. These are then filtered to remove digital artefacts and converted to single-ended audio, to be fed to RCA output sockets CON7a and CON7b.

Next month . . .

In the third and final article next month we'll have all the construction details, plus the test procedures after each stage of construction, to ensure that everything is working correctly before you proceed to the next step.

We'll then cover a final set of tests; how to download, install and set up the USB drivers, and some useful information on using the finished product.

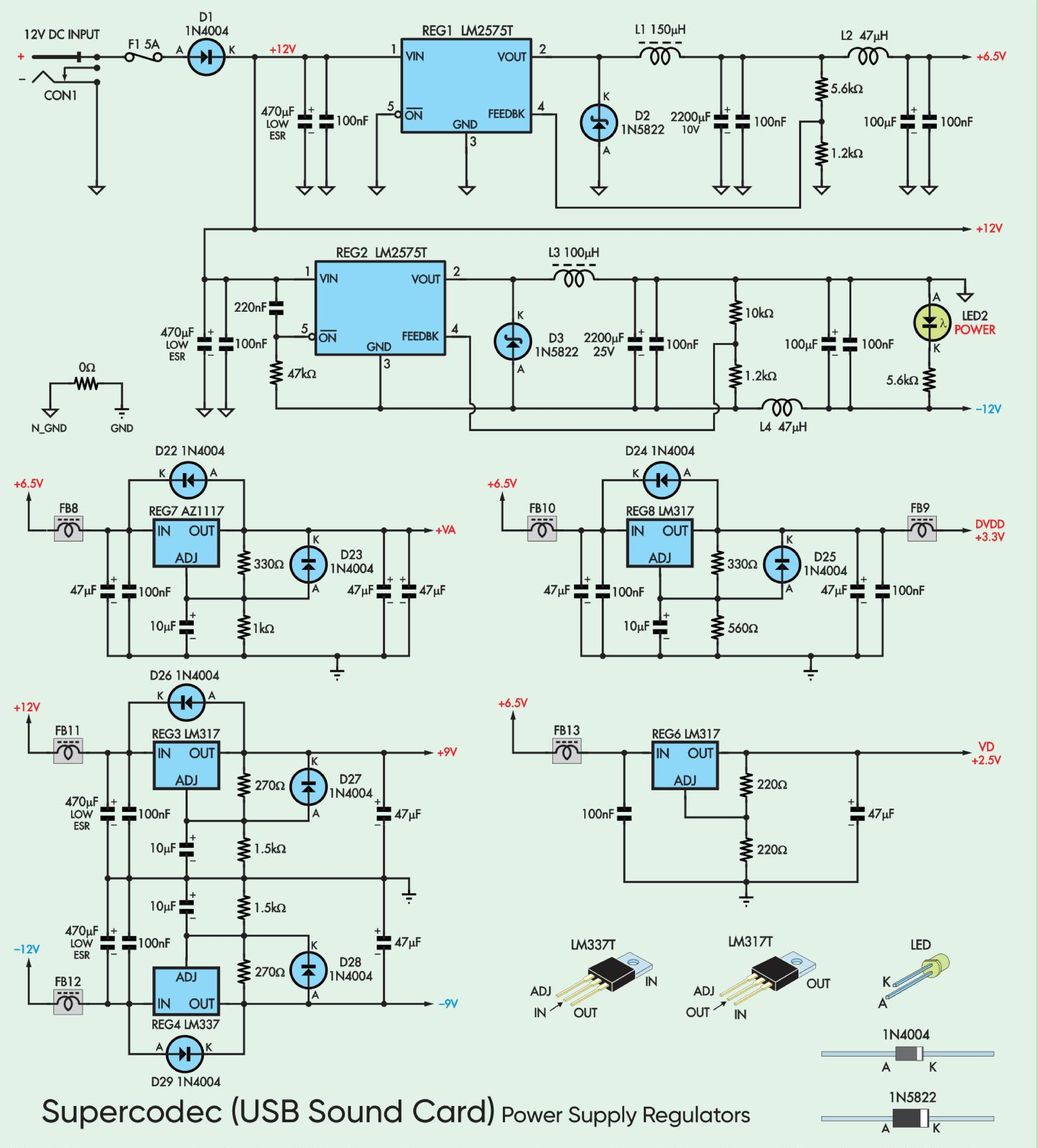

12V DC INPUT
+
–
CON1
F1 5A
D1
1N4004
A
K
+12V
REG1 LM2575T
1
VIN
VOUT
2
5
ON
FEEDBK
4
GND
3
470µF LOW ESR
100nF
L1 150µH
D2
1N5822
2200µF 10V
100nF
L2 47µH
5.6kΩ
1.2kΩ
100µF
100nF
+6.5V
+12V
REG2 LM2575T
220nF
47kΩ
470µF LOW ESR
100nF
L3 100µH
D3
1N5822
2200µF 25V
100nF
10kΩ
1.2kΩ
100µF
100nF
LED2
POWER
5.6kΩ
L4 47µH
–12V
0Ω
N_GND
GND
D22 1N4004
+6.5V
FB8
REG7 AZ1117
IN
OUT
ADJ
330Ω
D23
1N4004
47µF
100nF
10µF
1kΩ
47µF
47µF
+VA
D24 1N4004
+6.5V
FB10
REG8 LM317
330Ω
D25
1N4004
47µF
100nF
10µF
560Ω
47µF
100nF
FB9
DVDD
+3.3V
D26 1N4004
+12V
FB11
REG3 LM317
270Ω
D27
1N4004
470µF LOW ESR
100nF
10µF
1.5kΩ
47µF
+9V
10µF
1.5kΩ
47µF
–12V
470µF LOW ESR
100nF
270Ω
D28
1N4004
FB12
REG4 LM337
D29 1N4004
–9V
+6.5V
FB13
REG6 LM317
220Ω
220Ω
100nF
47µF
VD
+2.5V
LM337T
ADJ
IN
OUT
IN
LM317T
ADJ
OUT
IN
OUT
LED
K
A
1N4004
A
K
1N5822
A
K
Supercodec (USB Sound Card) Power Supply Regulators

Fig.16: the power supply circuitry efficiently produces five very clean supply rails from the possibly noisy 12V DC input. These are ±9V for the op amps, +5V for the ADC and DAC chips, +3.3V for the digital section of the DAC chip and the two ASRC chips (IC6 and IC7) plus the isolator (IC12) and +2.5V for DC-biasing the analogue signals fed to the ADC. The ADC also has a local regulator (REG5) to produce its 3.3V digital rail from the +5V rail, as it was easier to lay out the board that way.

intentional, to maintain isolation between these domains.

The switchmode section that generates the –12V and –6.5V rails has a separate ground plane. At the output of this are the final 47µH/100µF filters. After that, there is a wire jumper from the 'noisy ground' at the input to the larger ground plane for the linear regulators. The aim here is to avoid allowing currents in the 'noisy ground' injecting noise into the remainder of the circuit.

There is also a vertical cut on the left-hand side of the ground plane which isolates the digital section from the power supplies. This ensures that the digital circuitry is operating in a ground plane largely separated from the analogue section, with the 'connection' being around the DVDD +3.3V output.

The aim is to avoid the digital circuitry injecting noise onto the analogue ground plane.

There is a ground plane across almost the entirety of the top of the board (bottom under the digital section), and ground fills everywhere practical.

So here we have a range of low-noise, carefully isolated power supplies that are distributed in a manner to minimise contamination of the analogue parts with any switching or digital noise.

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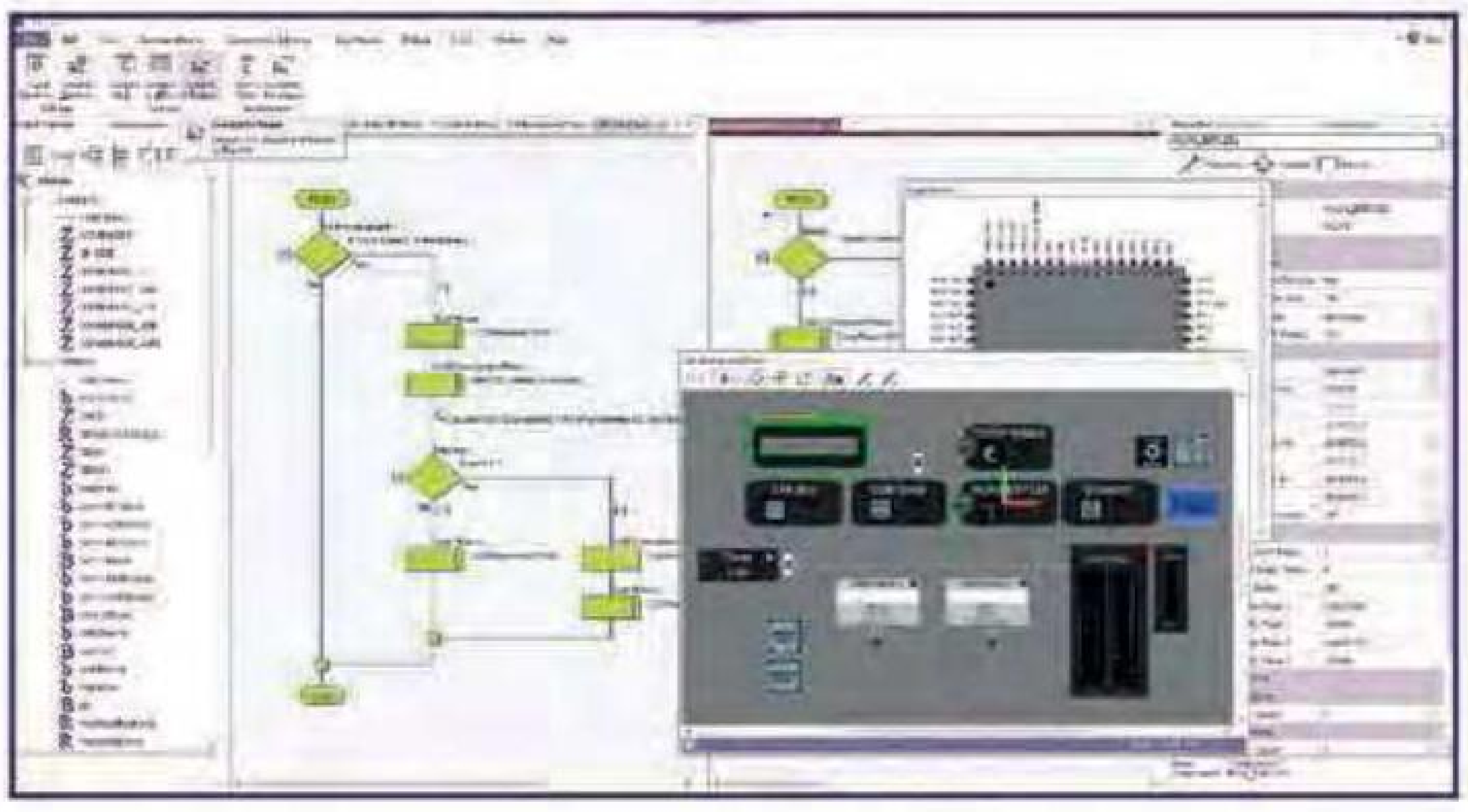

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This large and powerful *Ultrasonic Cleaner* is ideal for bulky items such as mechanical parts and delicate fabrics. Last month we described its features and explained how it works. Now let's move on to building it and getting it going!

Off
On
Level
On/Run
Start
Stop
Timer
SILICON CHIP Ultrasonic Cleaner

Part 2 – by John Clarke

ULTRASONIC High Power Cleaner

We explained in the article last month that the microcontroller in the *Ultrasonic Cleaner* uses three MOSFETs and a step-up transformer to produce around 100V AC to drive an ultrasonic transducer at just under 40W. This transducer is attached to the side of a vessel containing cleaning liquid and the objects to be cleaned. You select a power level and a time, and it does the rest.

The electronic components are mounted on two PCBs which are housed in a diecast aluminium box. The lid of the box has all the controls and the indicator LEDs.

The only external wiring is for 12V DC power to the unit (it draws around 4A at full power) and one twin lead which emerges from the box via a cable gland and goes to the transducer that's glued to the liquid vessel.

Building the *Ultrasonic Cleaner* isn't too difficult. The main steps are winding the transformer, soldering the components to the PCBs, drilling the case, mounting the parts in the case and wiring it up. We shall now describe all the necessary steps in detail.

PCB construction

The *Ultrasonic Cleaner* is built using two PCBs available from the *PE PCB Service*. The main PCB (code 04105201) measures 103.5 × 79mm; and the smaller front-panel PCB (code 04105202) measures 65 × 47mm.

The assembled PCBs are housed in a diecast box which measures 115 × 90 × 55mm. The overlay diagrams for both boards are shown in Figs.6 and 7.

Warning!

The transducer is driven at 100V AC which is more than enough to give you a shock. Touching both of the transducer terminals during operation will give you an electric shock, and it will be worse if your hands are wet. You must enclose the transducer in the PVC housing described in this article and only run it when so enclosed and attached to a bath filled to the correct level with cleaning fluid.

Start by fitting the resistors on both PCBs where shown. It's always best to check the values with a DMM set to measure resistance to make sure they're going in the right places.

The 0.1Ω SMD resistors mount on the top of the PCB, solder one end first and next check alignment before soldering the other end.

Continuing with just the main PCB, fit diodes D1 and D2 and make sure that their cathode stripes face toward the top edge of the PCB as shown. ZD1 can also be mounted, oriented as shown. We recommend that IC1 and IC2 are mounted in sockets. Make sure that the notched ends face toward the lower edge of the PCB. The three PC stakes can also be fitted now; they are marked as GND, TP1 and TP2 (you can leave these off and probe the PCB pads later, if desired).

Now mount REG1 flat onto the PCB with its leads bent down 90° to fit into the holes in the PCB. Secure it to the PCB using an M3 x 6mm screw and nut, then solder and trim its leads.

Also mount the 3AG fuse clips now, making sure that they have the correct orientation, with the end stops toward the outside of the fuse.

It is a good idea to insert the fuse before soldering the clips in place to ensure that

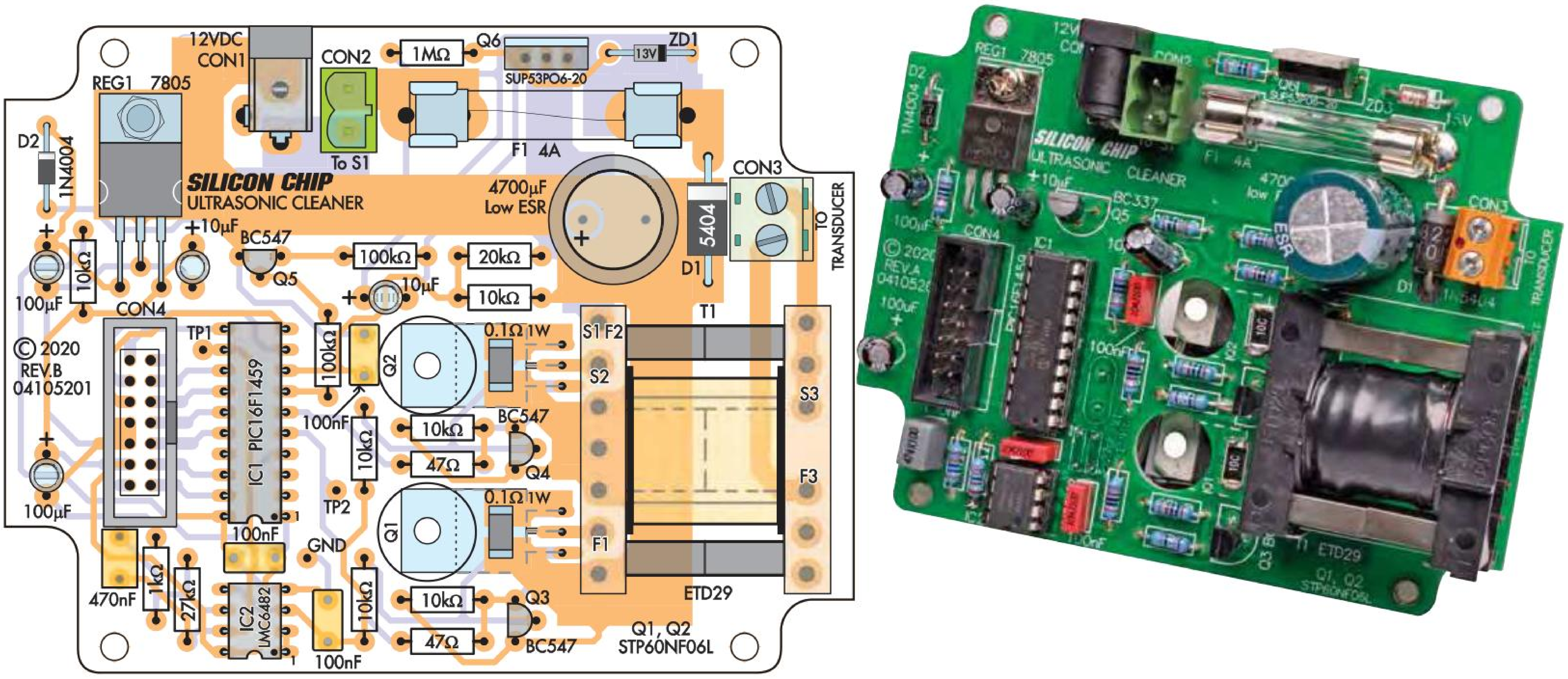

12VDC
CON1
CON2
To S1
1MΩ
Q6
SUP53PO6-20
ZD1
13V
REG1 7805
D2
1N4004
F1 4A
SILICON CHIP
ULTRASONIC CLEANER
4700µF
Low ESR
CON3
TO TRANSDUCER
5404
D1
+10µF
BC547
Q5
100kΩ
20kΩ
10µF
10kΩ
100µF
CON4
© 2020
REV.B
04105201
TP1
IC1 PIC16F1459
100kΩ
Q2
0.1Ω 1W
S1 F2
S2
S3
T1
100nF
10kΩ
47Ω
BC547
Q4
0.1Ω 1W
TP2
Q1
F3
F1
100nF
GND
470nF
1kΩ
27kΩ
IC2 LMC6482
100nF
10kΩ
10kΩ
47Ω
Q3
BC547
ETD29
Q1, Q2
STP60NF06L

Fig.6: fit the components to the main *Cleaner* PCB as shown here. Watch the orientation of the diodes, ICs, electrolytic capacitors and box header CON4. MOSFETs Q1 and Q2 are mounted on the underside, with their leads coming up through six pads next to transformer T1. Two holes in the PCB give access to their tabs, so that they can be mounted to the bottom of the case for heatsinking. This final version PCB is slightly different to the photo of the early prototype at right.

the fuse is aligned in the clips and that the clips are oriented correctly.

Ideally, the fuse clips should also be soldered on the top of the PCB on one side of each clip, to minimise the connection resistance.

The DC socket (CON1) and the 2-way pluggable terminal block socket (CON2) can then be installed. Take care with CON2's orientation; insert the plug into the socket before soldering the socket. This will ensure the orientation is correct, as the screws need to face towards the fuse so that the assembly will fit on the PCB. Also fit the 2-way screw terminal (CON3), with the wire entry toward the edge of the PCB.

Mount the 14-way IDC box header (CON4) now. Make sure the notch is oriented as shown and it is pushed all the way down before soldering its pins.

Fit the capacitors next, noting that the electrolytic capacitors must be oriented with the longer positive leads through the holes marked '+'. Then solder the three small transistors (Q3-Q5), which are all BC547s.

MOSFET Q6 (the SUP53P06-20) is mounted vertically with the mounting hole 22mm above the top of the PCB. MOSFETs Q1 and Q2 mount on the underside of the PCB. Bend the three leads for each MOSFET upward by 90°, 5mm from the bottom edge of the MOSFET body. Then insert the leads into the PCB from the underside, but do not solder them yet.

Now place the PCB into the enclosure, sitting on the internal mounting corners. Mark where the MOSFETs sit, including their mounting hole locations, then remove the PCB and place the silicone insulating washers at these locations. Fig.8 shows how these MOSFETs will be mounted, although we aren't attaching them to the case just yet.

Reinsert the PCB and adjust the MOSFETs so that they sit flat on the bottom of the case, on the silicone washers. Now solder the leads on the top of the PCB. Then remove the PCB and solder the leads on the bottom of the PCB as well. Similarly, for Q6, solder the leads on both sides of the PCB.

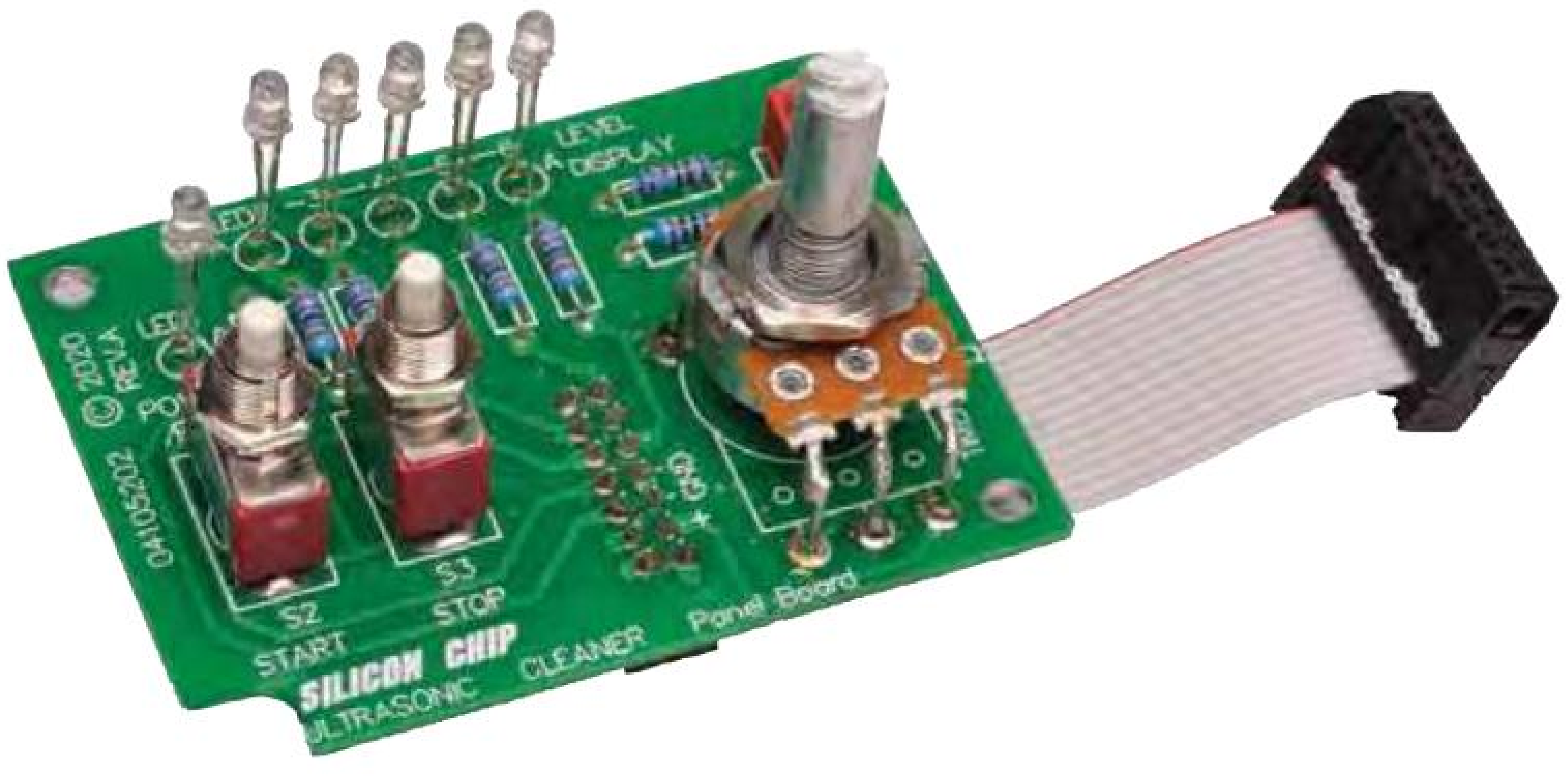
Winding the transformer

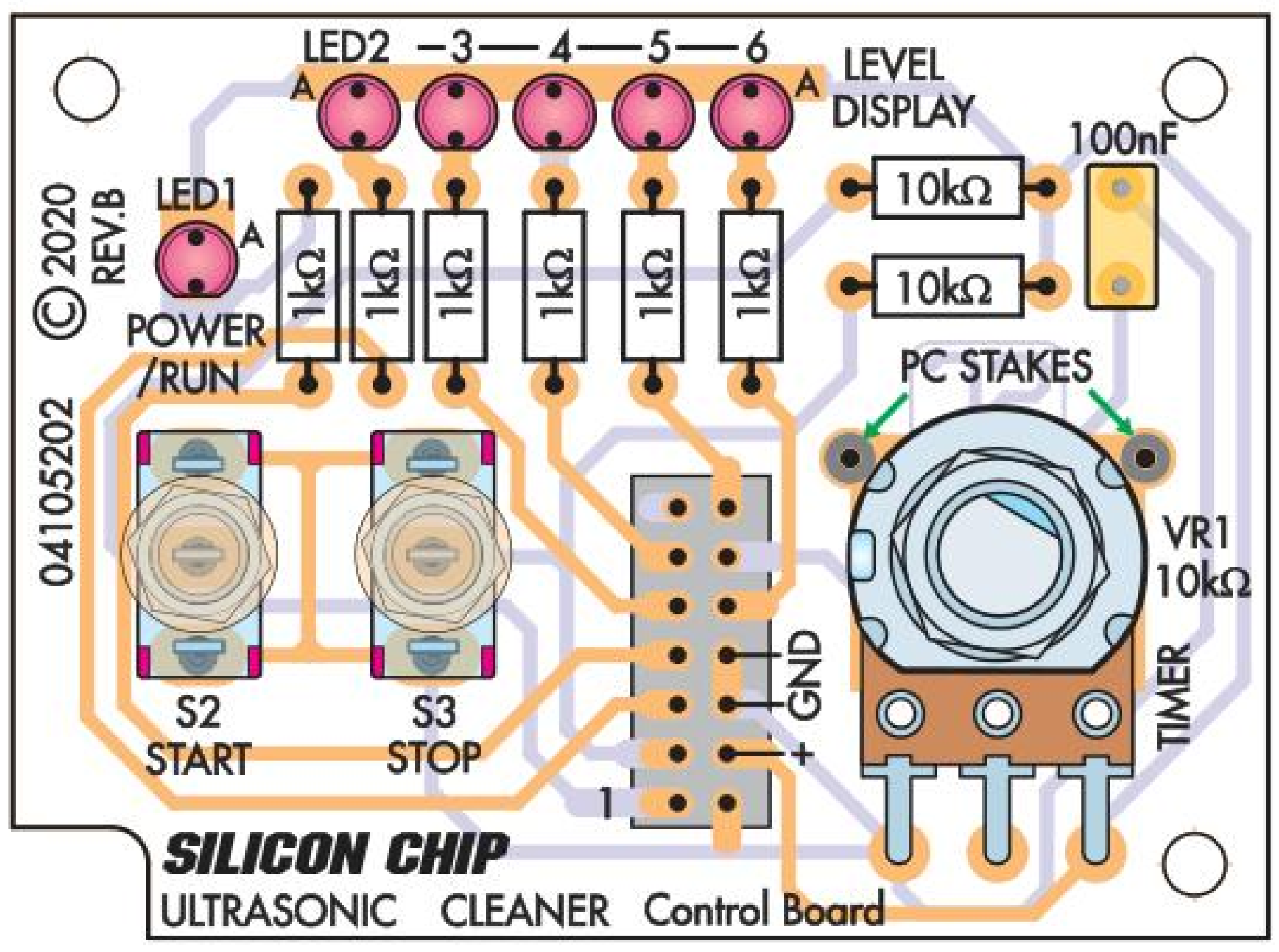
Fig.9 shows the transformer winding details. The primary windings are made from 1mm diameter enamelled copper wire (ECW) while the secondary winding uses 0.63mm diameter enamelled copper wire.

Start with the primary windings. First, cut two 400mm lengths of the 1mm ECW and remove the enamel from one end of each wire using fine emery paper or a hobby knife. Tin the wire ends and wrap one wire around pin 7 on the underside of the transformer bobbin, and the other onto pin 8. Solder both close to the bobbin.

Now close-wind seven turns of both wires (side-by-side) until the windings reach the opposite end of the former. The winding direction does not matter as long as both wires are wound together. Cover the windings in a layer of insulation tape.

Pass the wires back along the spine of the former. Using a multimeter on the ohms setting, find the wire that's terminated to pin 7 and terminate its other end to pin 12 in the same way as before. The other wire end terminates at pin 7. Cover the windings in a layer of insulation tape.




LED2
3
4
5
6
A
LEVEL DISPLAY
100nF
LED1
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REV.B
04105202
POWER /RUN
1kΩ
1kΩ
1kΩ
1kΩ
1kΩ
1kΩ
10kΩ
10kΩ
PC STAKES
VR1
10kΩ
GND
+
TIMER
S2
START
S3
STOP
SILICON CHIP
ULTRASONIC CLEANER Control Board

Fig.7: IDC header CON5 mounts on the back of this front panel board, while the LEDs, switches and potentiometer VR1 protrude through holes in the front panel. Make sure that VR1's body is grounded via the pads provided and also check that the LEDs are all oriented as shown.

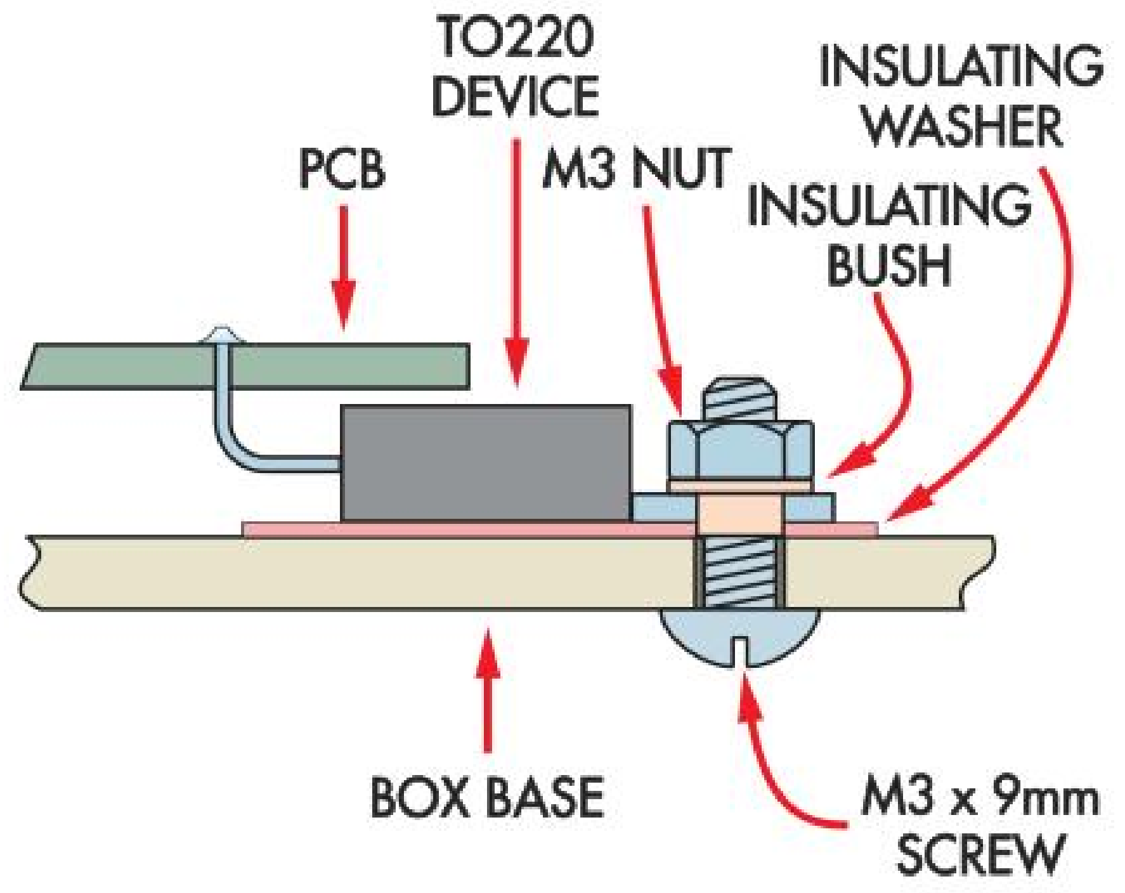
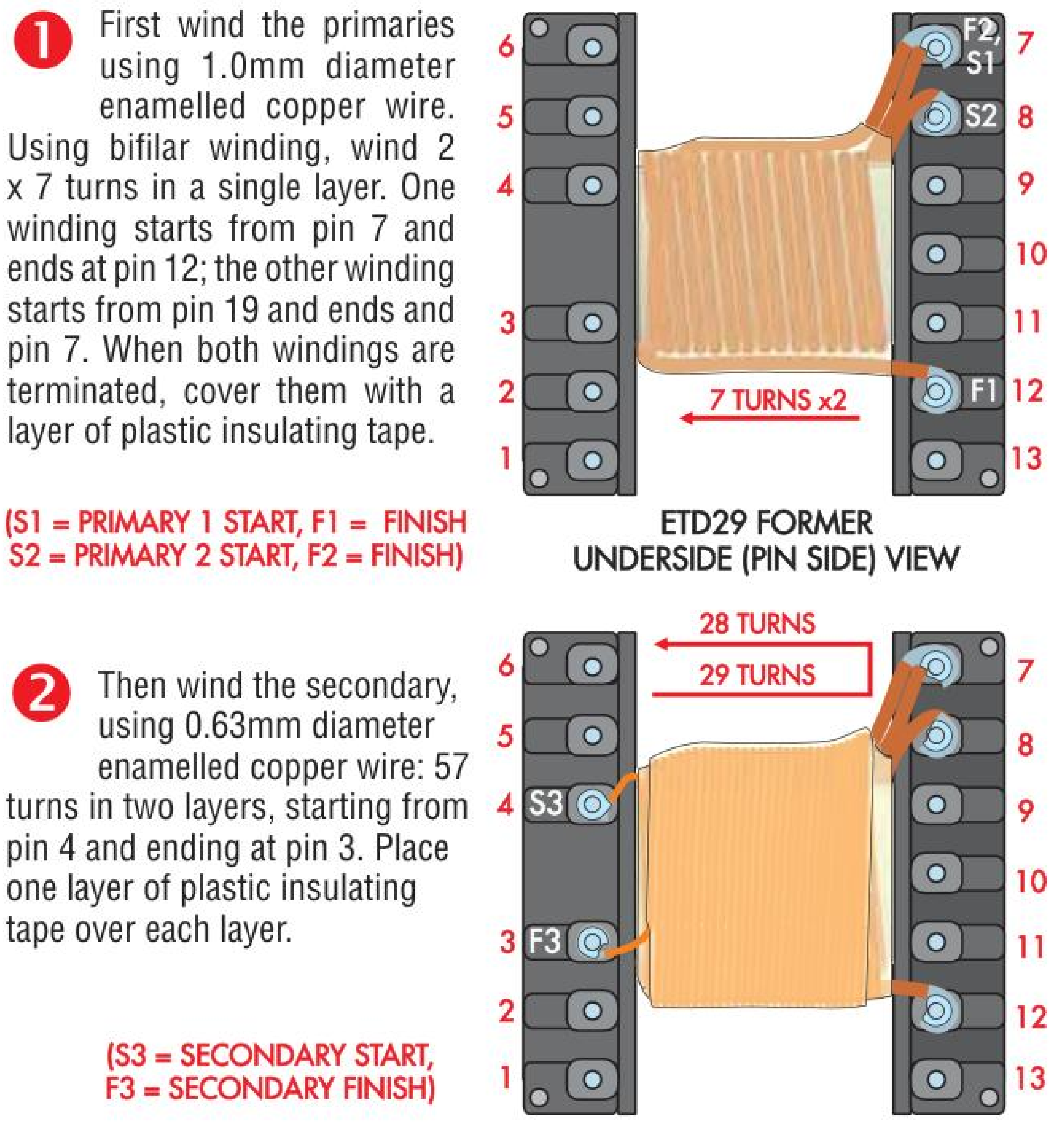


Fig.8: this is how the MOSFETs are mounted to the board and the case (for heatsinking). Ensure that the tabs are fully isolated from the case before powering the *Cleaner* up. Initially, the MOSFETs can be attached to the outside of the box for testing, then later moved to the inside (the mounting method is the same either way).

Fig.9: follow these transformer winding instructions carefully, to make sure that your finished transformer has the correct phasing and turns ratio.


① First wind the primaries using 1.0mm diameter enamelled copper wire. Using bifilar winding, wind 2 x 7 turns in a single layer. One winding starts from pin 7 and ends at pin 12; the other winding starts from pin 19 and ends and pin 7. When both windings are terminated, cover them with a layer of plastic insulating tape.

(S1 = PRIMARY 1 START, F1 = FINISH
S2 = PRIMARY 2 START, F2 = FINISH)

② Then wind the secondary, using 0.63mm diameter enamelled copper wire: 57 turns in two layers, starting from pin 4 and ending at pin 3. Place one layer of plastic insulating tape over each layer.

(S3 = SECONDARY START,
F3 = SECONDARY FINISH)

The secondary winding uses the 0.63mm ECW. Terminate one end to pin 3 and wind on 29 turns (the direction does not matter). Then wrap a layer of insulation tape over this winding and continue winding back over the first layer, in the same direction as before (clockwise or anticlockwise) to complete 57 turns. Terminate this to pin 4.

Once wound, slide the cores into the former and secure with the clips. These clips push on to the core ends and clip into lugs on the side of the bobbin.

It is best not to install the transformer directly onto the PCB just yet. It can be temporarily wired up using some short lengths of 0.7mm diameter tinned copper wire or similar, between pins 3, 4, 7, 8 and 12 of the transformer and the PCB pads for those pins. This is so that it will be easier to change the secondary windings, should the ultrasonic transducer require fewer or extra turns. More on this later.

Now insert both IC1 and IC2 into their sockets, taking care to orient them as shown on the overlay diagram.

Front panel control board assembly

There are only a few parts left on this PCB, but be careful to mount them on the correct side. Most parts go on the top side, but the 14-way IDC transition header (CON5) goes on the underside. Fit CON5 first, taking care to orient it with the pin 1 triangle as shown in Fig.7. Solder from the top side of the PCB.

Now the IDC cable needs to be attached to this header. Fig.10 shows how the IDC cable is arranged in CON5. The wire can be secured by adding a small piece of soft timber (eg, pine) over the soldered pins on the PCB and another piece of timber on the other side of the PCB, and compressing the lot with a G-clamp or bench vice.

The other end of the IDC cable goes to the socket, again taking care to orient the socket correctly with the locating tab as shown. Compress as before, with protective timber and a G-clamp or bench vice (or use a specialised tool like Altronics Cat T1540).

The resistors can also now be installed, if you haven't already. Also insert the five PC stakes from the top side of the PCB for the potentiometer mounting and connections, and fit the 100nF capacitor.

The remaining assembly work for this board is done after the enclosure lid has been prepared. Cut the potentiometer shaft so that it is 12mm long from the threaded boss, or to suit the knob used.

The front panel label (Fig.11) shows the position of the LEDs, power, start and stop switches and the potentiometer on the lid. This label can also be downloaded as a PDF file from the October 2021 page of the *PE* website. Print it and attach it to the lid, ensuring that the paper template is centred correctly. Mark out and cut the holes. The hole for the power switch can be made by drilling a series of small holes around the perimeter, knocking out the piece and filing to shape until the switch fits and is held in position firmly.

Break off the locating spigot on the potentiometer and mount the potentiometer onto the lid. Place the washer between the pot and lid, with the nut on the outside of the lid. Also attach the switches, with one nut on either side of the lid. Switch orientation doesn't matter.

Insert the LEDs into their pads from the top side of the PCB, taking care to orient them all with the longer lead (anode) going into the pads marked 'A'. Do not solder the LEDs in yet.

Place the PCB onto the switch terminals and solder them in place. Scrape off the coating on the pot body where the two mounting PC stakes are to solder to the pot body (don't inhale the dust). This allows the solder to wet the pot body for a good solder joint. Solder the PC stakes to the pot terminals after bending the pot terminals over to meet the PC stakes.

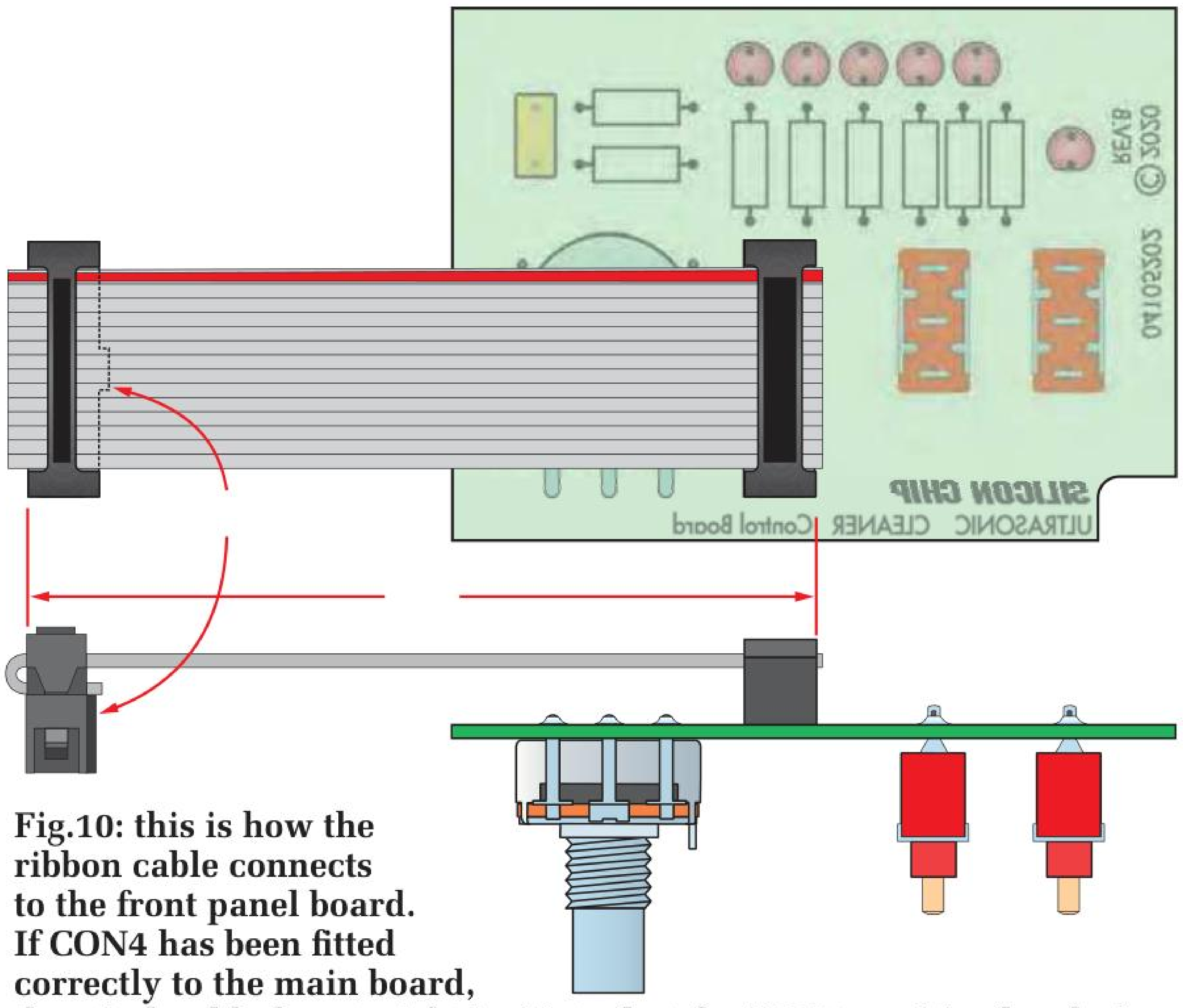
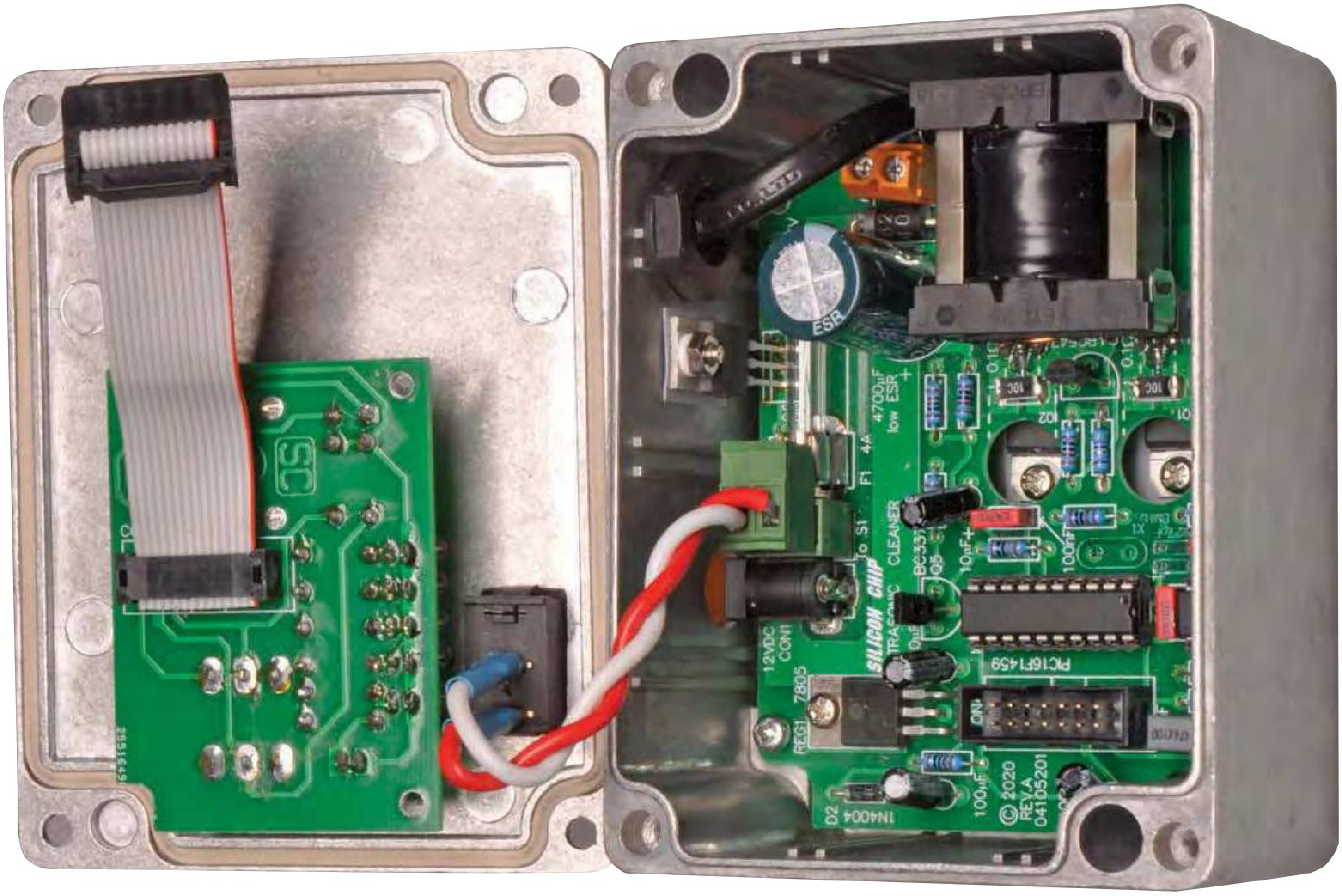


Fig.10: this is how the ribbon cable connects to the front panel board. If CON4 has been fitted correctly to the main board, then it should plug straight in. Note that the 'IDC transition header' used for CON5 on the front panel board is captive, ie, there is no socket. Its pins are soldered directly to the PCB.



The finished controller shown 'opened out', albeit with the ribbon cable disconnected from CON4.

The LEDs can now be pushed up into the holes on the lid and soldered in place, then trimmed.

The PCB is held in position by the switches and potentiometer. There is no need for extra support. If you absolutely must, you could attach 15mm-long standoffs to the corner holes.

Front panel label

The front panel label can be made using overhead projector film, printing the label as a mirror image so that the ink will be between the enclosure and film when affixed. Use projector film that is suitable for your printer (either inkjet or laser) and affix using clear neutral-cure silicone sealant. Roof and gutter silicone is suitable. Squeegee out the lumps and air bubbles before the silicone cures.

Once cured, cut out the holes through the film with a hobby or craft knife.

Two holes are required in the side of the box for the DC power connector and the ultrasonic transducer lead, plus one for mounting Q6. The locations and sizes are shown in Fig.12.

Holes are also required in the base of the enclosure for mounting MOSFETs Q1 and Q2. You should have marked the positions earlier; drill these to 3mm. Lightly countersink these holes inside the enclosure, plus the one for Q6 on the side, to prevent the insulating washer from being damaged by a rough hole edge.

Also lightly countersink the holes for Q1 and Q2 on the outside of the enclosure. This is so these MOSFETs can be mounted temporarily on the outside of the enclosure for testing purposes. This way, you will have better access to the PCB for testing and fixing any problems without having to remove it from the box.

Fit the four M3 × 9mm standoffs to the underside of the PCB using 6mm screws, then attach MOSFETs Q1 and Q2 using silicone washers, insulating bushes and M3 screws and nuts, as shown in Fig.8.

Check that the metal tabs are isolated from the case using a multimeter on a high ohms setting. A reading in the megohm region means that isolation is good. Lower readings indicate a shorted connection to the case.

Wire switch S1 to the board using 5A-rated hookup wire, with heatshrink tubing over the soldered terminations. Once the other ends of the wires are secure in the screw terminals for CON2, plug it into the CON2 socket.

Preparing the ultrasonic transducer

There are many suitable 50W/60W 40kHz ultrasonic transducers available online – see last month's parts list for a device readily available in the UK. (Depending on your location / shipping costs, these sellers are also worth trying: **https://bit.ly/pe-oct21-us1** and **https://bit.ly/pe-oct21-us2**)

The wiring can be soldered to the transducer terminals; 0.75mm^2 figure-8 wire or sheathed dual cable is suitable. The terminals on the transducer are exposed and need to be protected within a housing to prevent accidental contact as they are a shock hazard.

The 100V AC can cause a nasty shock, but only if both contacts are touched.

Touching one contact or the front face of the transducer will not cause a shock since the transformer output is floating from the main circuit. Howevver, do not rely on this to protect you!

A suitable housing can be made using 50mm PVC DWV (Drain, Waste and Vent) fittings. We used an end cap and a screw thread adaptor (with the screw thread section cut off) to extend the length of the end cap to an overall outside length of 50mm. You could use the end cap and a short length of 50mm pipe instead of the adaptor.

Wire entry is via a cable gland that is secured in the side of the end cap. Place the cable gland hole in the side of the end cap, allowing sufficient room for the nut inside. The adaptor or pipe will require an area removed

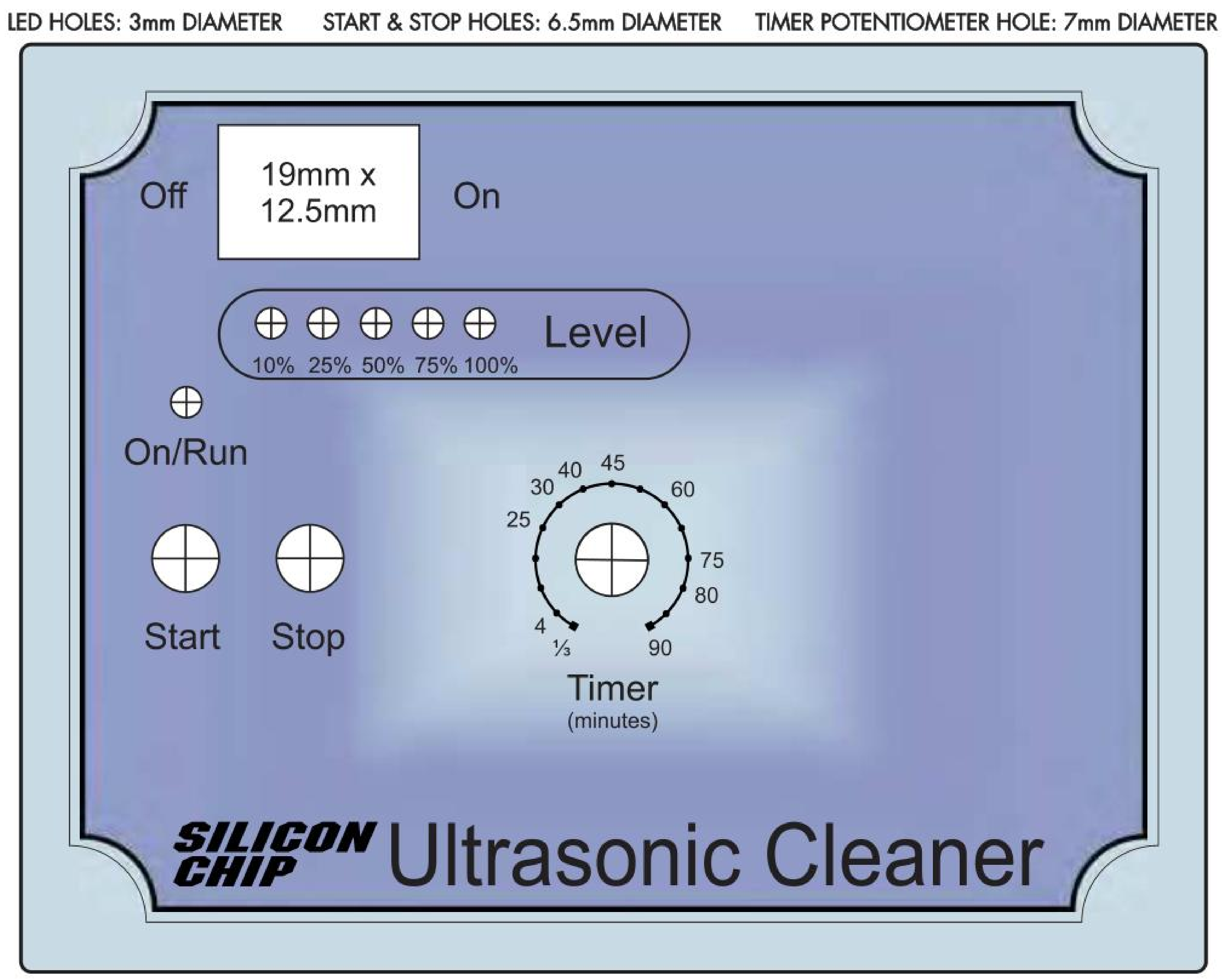


Fig.11: the lid/front panel artwork for the *Ultrasonic Cleaner*, which also serves as the lid drilling/cutting template. You can download this as a PDF file from the October 2021 page of the *PE* website, print it and optionally laminate it (or print onto adhesive label paper – see the text for more details).

with a file so that it clears the gland nut when inserted into the end cap.

The terminals on the transducer will need to be bent over at their ends to fit into the housing.

The transducer should be mounted within the enclosure using neutral-cure silicone sealant (such as roof and gutter sealant). Use just sufficient silicone to secure the transducer to the inside of the housing, around the outside of the lower bell-shaped section. Fully potting it in silicone will dampen the ultrasonic movements a little.

The face of the transducer should be kept clear of the sealant. This is so that the transducer can be secured to the outside of the bath with an epoxy resin.

Connect the ultrasonic driver cable to the PCB at CON3. Make sure there are no strands of copper wire emerging from the terminals which could short out. The other ends of this cable connect to the ultrasonic transducer.

Testing

Before testing, insert the 3AG fuse into the clips if you haven't already done so. If you're powering the unit from a battery, or your power supply doesn't already have a DC barrel plug to match the socket on the *Cleaner*, attach the plug to the end of the power supply wires.

When ready, apply power to the circuit and check the main 5V supply between pins 20 and 1 of IC1 and between pins 4 and 8 for IC2. You should get a reading of 4.75-5.25V across these pins.

When first powered up and after the Start switch is pressed, the *Ultrasonic Cleaner* will run the calibration for the transducer. While you can do that now, as long as the transducer is attached, the calibration will be incorrect. This is because the impedance of the transducer differs between when unloaded and loaded.

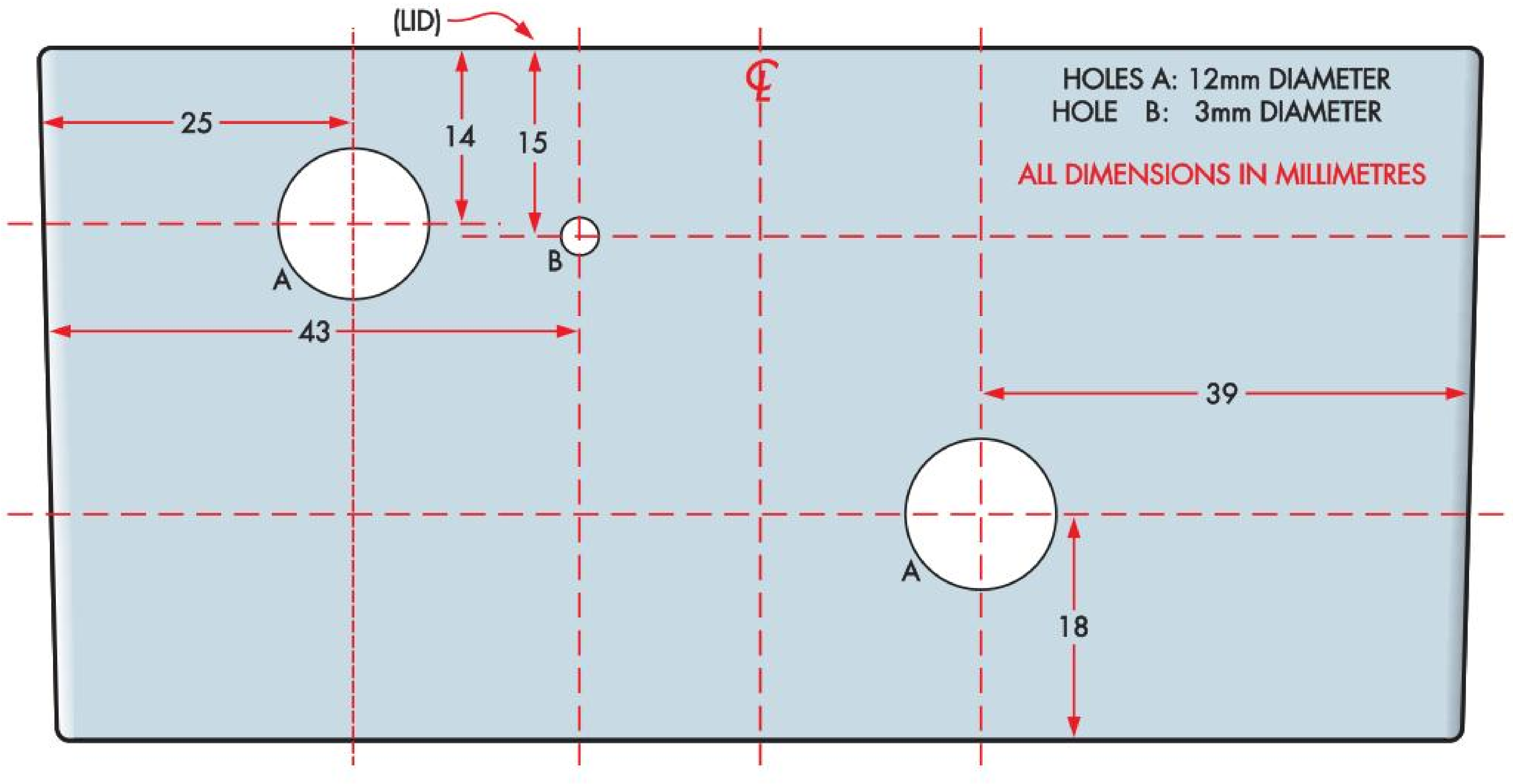


Fig.12: only three holes need to be drilled in the side of the case, two 12mm and one 3mm in diameter. The 3mm hole is for mounting the tab of MOSFET Q6, while the others are for the DC socket and transducer cable gland.

When loaded (by attaching to the bath with fluid), the impedance is higher, so if you run it now, it will need to be re-calibrated later. The procedure to do that is described in the *Calibration* section below.

Once calibrated, the power level will be shown, and the power LED will light once the transducer is being powered at the set level.

If no transducer is connected, the power LED will go out momentarily and one or two level LED(s) will light. Then the level LED or LEDs will extinguish, and the power LED will relight. No calibration will occur.

To properly test the board, you need to have the transducer at least temporarily attached to a suitable vessel, filled with a liquid such as water. That's because you need to check that the transformer is supplying the right voltage to achieve full power. Your transducer could differ from the one we have used, either by being a different type or just coming from a different batch.

Diagnostics

We have included a diagnostic display for the power level so that you can check whether your transducer is delivering full power. With the unit powered up and the transducer connected and attached to a bath, set the power level to 100%. The display will indicate if the transducer can or cannot deliver full power. If it can, the 100% LED will stay lit.

If the transducer cannot deliver that power level, the power will begin to reduce automatically until it shows what can actually be produced by the transducer.

If this happens to you, you may be able to achieve full power by removing water from the bath. However, this may leave you with insufficient water for practical cleaning. If you decide to lower the water level, make sure to re-run the calibration procedure (see below) before testing for full power again.

The alternative to reducing the water level is to add more turns on the secondary of transformer T1. This will increase the transducer drive voltage to allow the extra

Here's the transducer (left) and mounted inside our 'plumber's special' DWV PVC 'case'. This photo was taken before we secured the transducer to the 'case' with neutral-cure silicone sealant.

power to be delivered. How many turns need to be added can be determined on a trial-and-error basis.

Once full power is possible, the transducer may not be able to be driven at the very low power levels. This can be determined by setting the level to the lowest setting. If this low power is not possible, the level display will increase by itself to a higher level, indicating the lowest power level available.

Note that the over-current indication (the left, middle and right level LEDs flashing simultaneously) may show instead. If so, that suggests you have too many turns on the transformer secondary (see the *Troubleshooting* section below)

The lowest power level available will depend on the steepness of the transducer's power/frequency curve. This is a measure of how sharply the power drops away when off-resonance. Steep sides on the power/frequency curve for the transducer will mean that it can be driven at the lowest power.

In contrast, other transducers with shallower curves might only be able to be operated one level above the minimum (ie, 20% rather than 10%).

Finalising construction

Once you are happy with the available power range, detach the PCB from the case. Transformer T1 can now be permanently installed on the PCB, rather than via short lengths of connecting wire.

Before fitting the PCB in the box, disconnect the ultrasonic driver cable (making sure that the power is off!), then feed its cable through the cable gland, the hole in the enclosure and the gland securing nut, then re-connect it to CON3. Make sure there are no strands of copper wire emerging from the terminals which could cause a short.

The three MOSFETs are attached to the inside of the enclosure using the silicone washers and insulating bushes, M3 screws and nuts. Refer to Fig.8 (the same as before, but this time on the inside). Once again, check that the metal tabs are isolated from the case using a multimeter set for reading ohms, using the same procedure as before.

The PCB is secured to the enclosure using the two supplied screws. Insert the supplied Neoprene seal in the lid channel and cut it to length before attaching the lid using the screws provided. Finally, stick the four rubber feet to the base.

Calibration

As mentioned earlier, calibration happens automatically the first time you press the Start switch. To re-calibrate the unit, hold down the Stop switch, press the Start switch and then release both.

This should be done while the transducer is loaded, ie, attached it to the fluid-filled bath.

Running the transducer unloaded will cause a large current flow to the transducer due to its lower impedance. While the circuit prevents excessive current by switching off, it is still a good practice to avoid driving the transducer except when under load.

During calibration, the resonance of the transducer will be found and stored in non-volatile Flash memory. This means that the unit doesn't have to find the resonance frequency each time the *Cleaner* is used.

At the beginning of the calibration procedure, all five level LEDs will light, and then they will switch off. See the troubleshooting section if you are experiencing problems with the calibration.

Using the timer

When cleaning parts, set the timer for the maximum duration you want. The time can be changed while the *Cleaner* is running, and it will use the new time, providing that it is longer than what has already transpired.

Setting to a time setting to less than what has already transpired will cause it to stop immediately, as will pressing the Stop button.

Troubleshooting

If you are having difficulty achieving calibration, you can run a more comprehensive diagnostics routine that will provide more information.

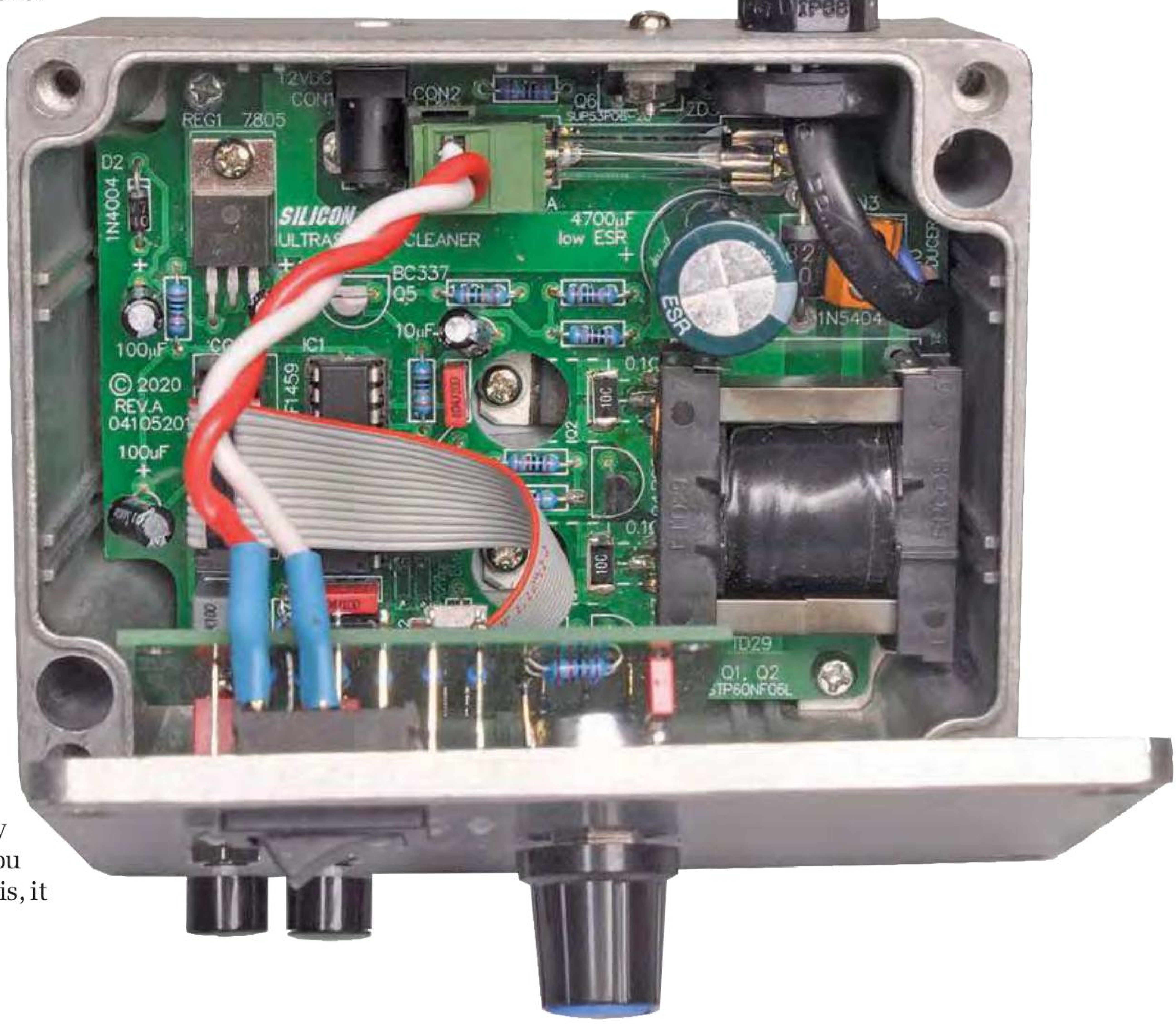
This is initiated by switching the power off, waiting 10 seconds, then pressing and holding the Start and Stop switches together while switching on the power. The diagnostics routine will start, as indicated by all five level LEDs lighting up.

In this mode, the frequency to the ultrasonic transducer can be manually adjusted using the timer potentiometer (VR1). The frequency is 40kHz when the timer pot is set midway and can be varied from 37.6kHz to 42.4kHz by rotating VR1.

Further frequency changes can be made by setting the pot either fully anticlockwise or fully clockwise and pressing the

Here's the transducer glued to the cleaning bath (in this case a stainless steel cooking tray). We used J-B Weld, a two-part epoxy which we find works better than any other.

Another view of the PCBs sitting inside the diecast box – one mounted on the lid. Here you can clearly see one of the two MOSFETS with its mounting screw accessible through the hole in the PCB. Don't forget the insulating washer and bush underneath!



Start switch. When holding the pot fully anticlockwise and pressing the Start switch, the frequency will drop by about 540Hz so that overall adjustment range is 540Hz lower, ie, 37.06-41.86kHz rather than 37.6-42.4kHz.

You can reduce this further in 540Hz steps to a minimum of 34.88kHz with the pot fully anticlockwise, by pressing the Start switch repeatedly with VR1 at its fully anticlockwise position

Similarly, the frequency range can be increased in 540Hz steps by holding the pot fully clockwise and pressing the Start switch. The maximum frequency can be increased up to 45.45kHz by doing this repeatedly.

You can monitor the drive frequency by connecting a frequency counter or meter at TP2. You can monitor the current draw with a voltmeter at TP1. You don't really need to know the frequency, so if you don't have the means to measure this, it is not critical.

The most critical measurement is the current readings at TP1. Adjust VR1 to find the resonance point, where the current is at a maximum.

For the transducer to be able to deliver full power, the current measurement at TP1 needs to be 4.2V just below or above resonance. 4.2V equates to 300mV across the 0.1Ω resistors, so a 3A current. With a 12V supply, this represents a 36W power delivery.

If there is a current overload and the voltage at TP1 goes above 4.8V, the transducer drive will be cut off. This is to limit power applied to the transducer to a safe level. Overload is indicated by the outside and centre LEDs on the level display lighting. The drive is restored momentarily every two seconds to check the current. Adjust the potentiometer to restore continuous drive.

You can also press the Stop switch to switch off the transducer. To resume, you need to switch off the power and reenter the diagnostics routine as described above.

As mentioned previously, if at the resonance there is an insufficient voltage at TP1, then you will need more secondary turns on the transformer (or take water out). The correct number of turns or amount of water is when the TP1 voltage is close to 4.5V at resonance. This allows some leeway in frequency control to achieve 4.2V at TP1, for 36W into the transducer when slightly off-resonance.

If the TP1 voltage when approaching resonance is too high (ie, above 4.5V), reduce the number of secondary turns or use more water in the bath.

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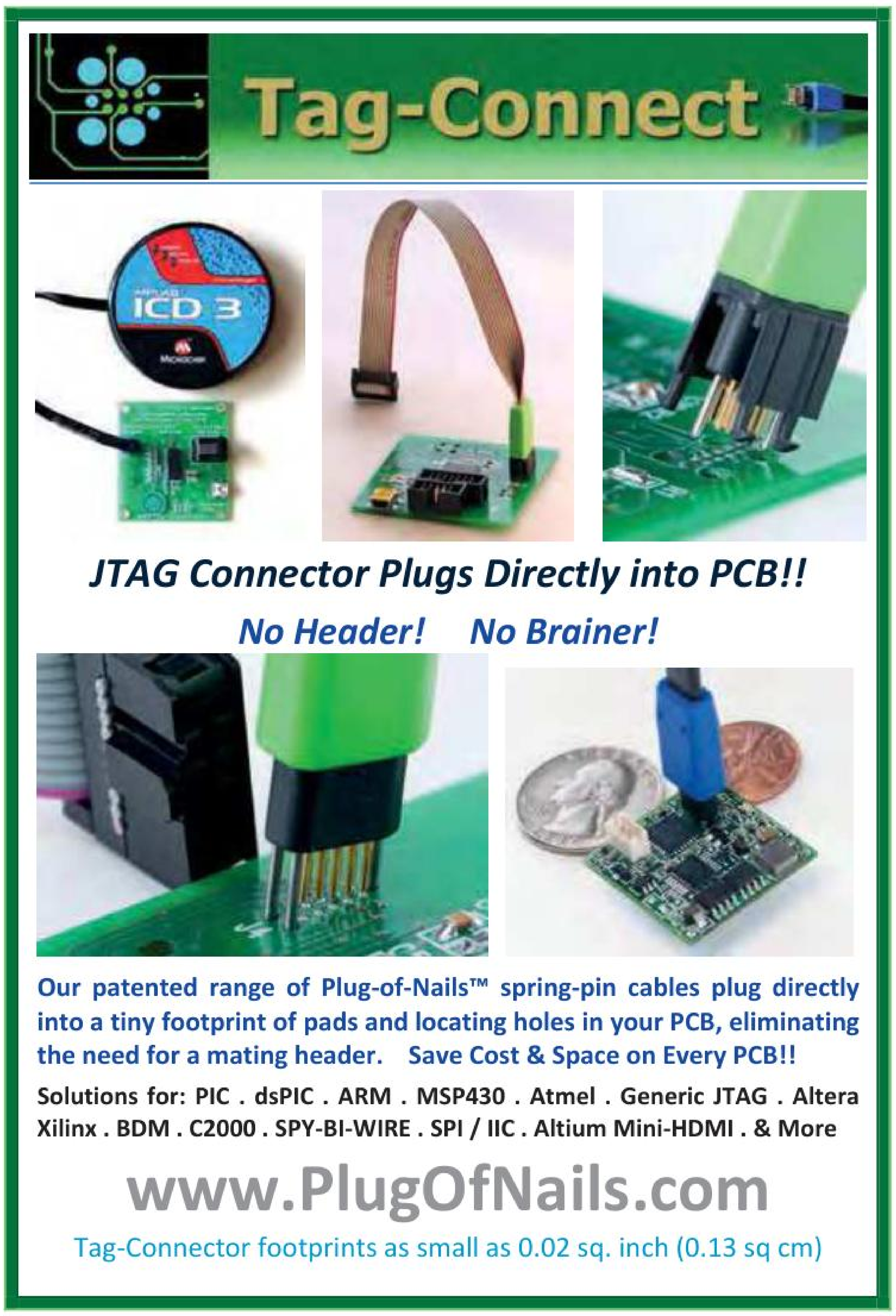

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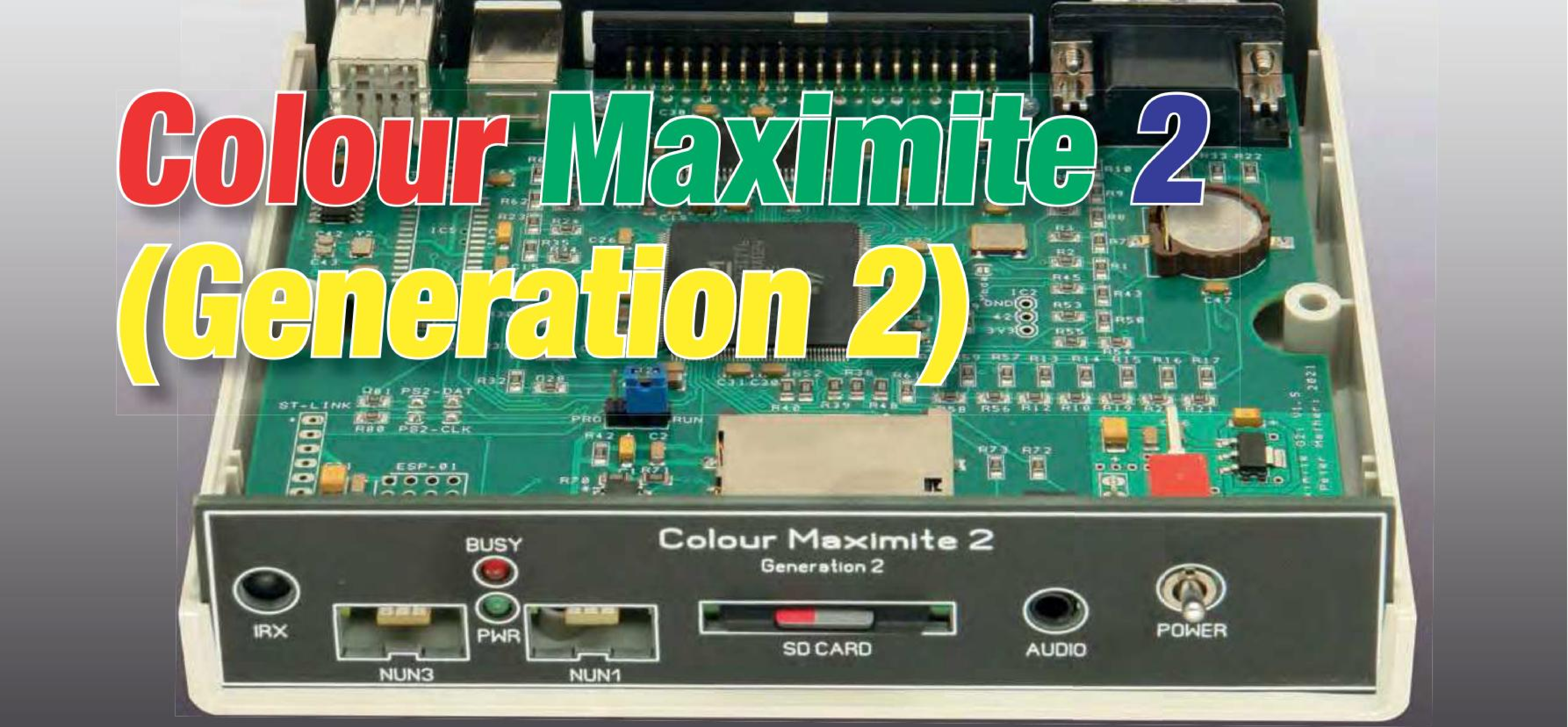


Part 1

Words Phil Boyce

Design Geoff Graham

Firmware Peter Mather

The latest iteration of our retro home computer

Back in November 2019, we published a project that described the original *Colour Maximite* computer. The *Colour Maximite* computer (*CMM*) proved to be extremely popular, with many hundreds of units sold globally. For those of you unfamiliar with the *CMM*, it can simply be regarded as a compact, standalone BASIC computer to which you attach a VGA monitor, PS2 keyboard and 5V USB power supply. ('BASIC' doesn't mean simple or under-powered; it was programmed using the BASIC language.) On power up, it is immediately ready to be used, much like the pioneering home computers of the 1980s (for example, the ZX Spectrum, VIC20 and BBC micro series). The version of BASIC that the *CMM* uses is known as 'MMBASIC' (*Maximite* BASIC), and for those of you that have been following the *Make it with Micromite* series, it is virtually identical to the version of MMBASIC used to program the Micromite.

The *CMM* is much more powerful than the 4MHz, 8-bit microprocessor-based computers of the 1980s. Those typically ran on 6502 or Z80 ICs, but the *CMM* uses an 80MHz, 32-bit microcontroller. In addition, it is very easy to interface external hardware to the *CMM* thanks to several input/output (I/O) connectors and supporting I/O MMBASIC commands.

The *CMM* is quite an old design, dating back to 2012, so in 2020, a new (and much improved) version was released. This was called the *Colour Maximite 2* (*CMM2*), but for various reasons, it was not featured in *PE*. However, last month a tweaked version of the *CMM2* was released; so now seems like the perfect time to introduce you to the *CMM2*, or more specifically, the tweaked version which is known as the *CMM2 Generation 2* (*CMM2 G2*, often just abbreviated to *G2*).

Before we get into the details of this new 'beast', it is worth reflecting on the previous *Maximite* models to appreciate how things have evolved over the last decade. Do also bear in mind that the first *Maximite* was the predecessor of the very popular Micromite that now features in many *PE* projects.

Maximite history

In late 2010, Geoff Graham, a talented Australian hobbyist, set himself a challenge to try and implement BASIC on what at the time was a new and powerful 32-bit PIC processor. This was not only a huge software challenge; but it would also involve some kind of hardware design on which, if he was successful, he could run his version of BASIC. Ultimately, he was aiming to recreate a 1980s home computer (a Tandy TRS80) on a single PIC32 chip, knowing that it would also make a great project for his local electronics magazine, *Silicon Chip*.

After several hardware variants, he ended up with a working design that

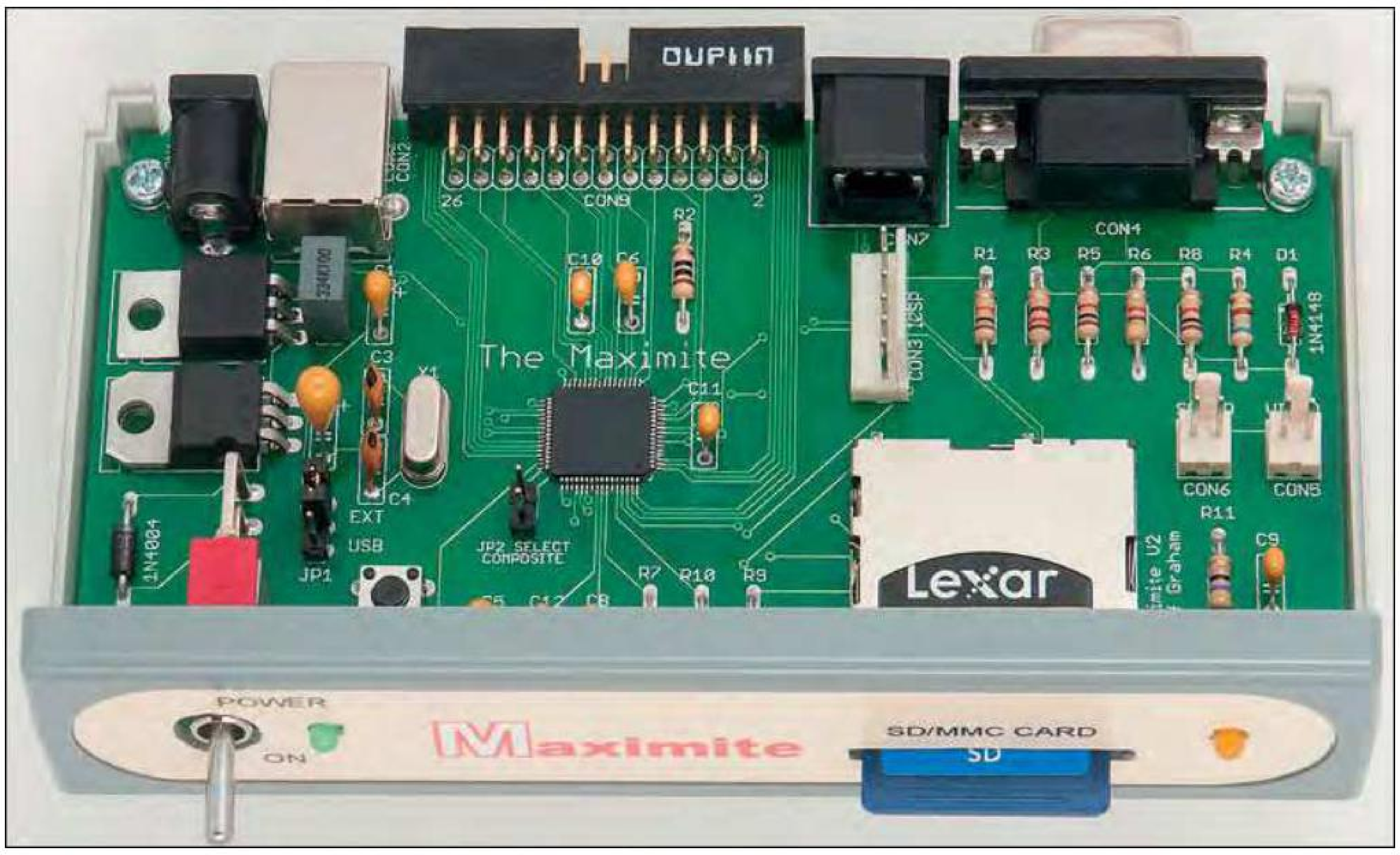


Fig.1. The first *Maximite Computer* was based on a PIC32 microprocessor. It was released in March 2011. The following year it became known as the *Monochrome Maximite*.

included an SD card (for program storage), a PS2 keyboard input (for entering program code), a VGA *monochrome* video output with a resolution of 480 × 432 pixels (for displaying the code and any other output), and an I/O connector for interfacing with external hardware. He had succeeded. It was indeed controlled by a single PIC32, all housed in a small plastic enclosure resulting in a neat, finished product (see Fig.1). He called it the *Maximite Computer*, and it was featured in *Silicon Chip* in 2011 (March, April, and May 2011 editions). The most impressive thing (at least in my opinion) is that all this was achieved in just over three months!

After the *Maximite Computer* had been created, Geoff brought out a trimmed-down version that did not include a VGA output, or an SD card. This version was named the *Mini Maximite* (see Fig.2), and it could be argued that this was the true pre-cursor to the now-popular Micromite. Once again, it was featured in *Silicon Chip* magazine (November 2011).

The Colour Maximite

Never one to rest on his laurels, Geoff looked at improving the design. Many of the earliest 1980s home computers were also initially monochrome, but then came colour. So, in September 2012, he upgraded the *Maximite Computer* to the *Colour Maximite* (*CMM*) (Fig.3), and it went on to become one of *Silicon Chip's* magazines most popular projects. Along with the ability to display colour graphics (up to eight colours when using 240 × 216-pixel resolution), it was also possible to draw coloured sprites (a two-dimensional image or animation that is integrated into a larger scene). It could play some very impressive sounds, including stereo MOD music files. It was even possible to insert a compatible Arduino shield directly onto the PCB, as well as having an option to add an RTC (real-time-clock) chip with battery back-up. As mentioned above, the *CMM* was featured in *PE* in 2019/2020 (November to January) and has been extremely popular here in the UK, and also across Europe and the US. (Note that the launch of the *Colour Maximite* resulted in the first *Maximite* becoming known as the *Monochrome Maximite*.)

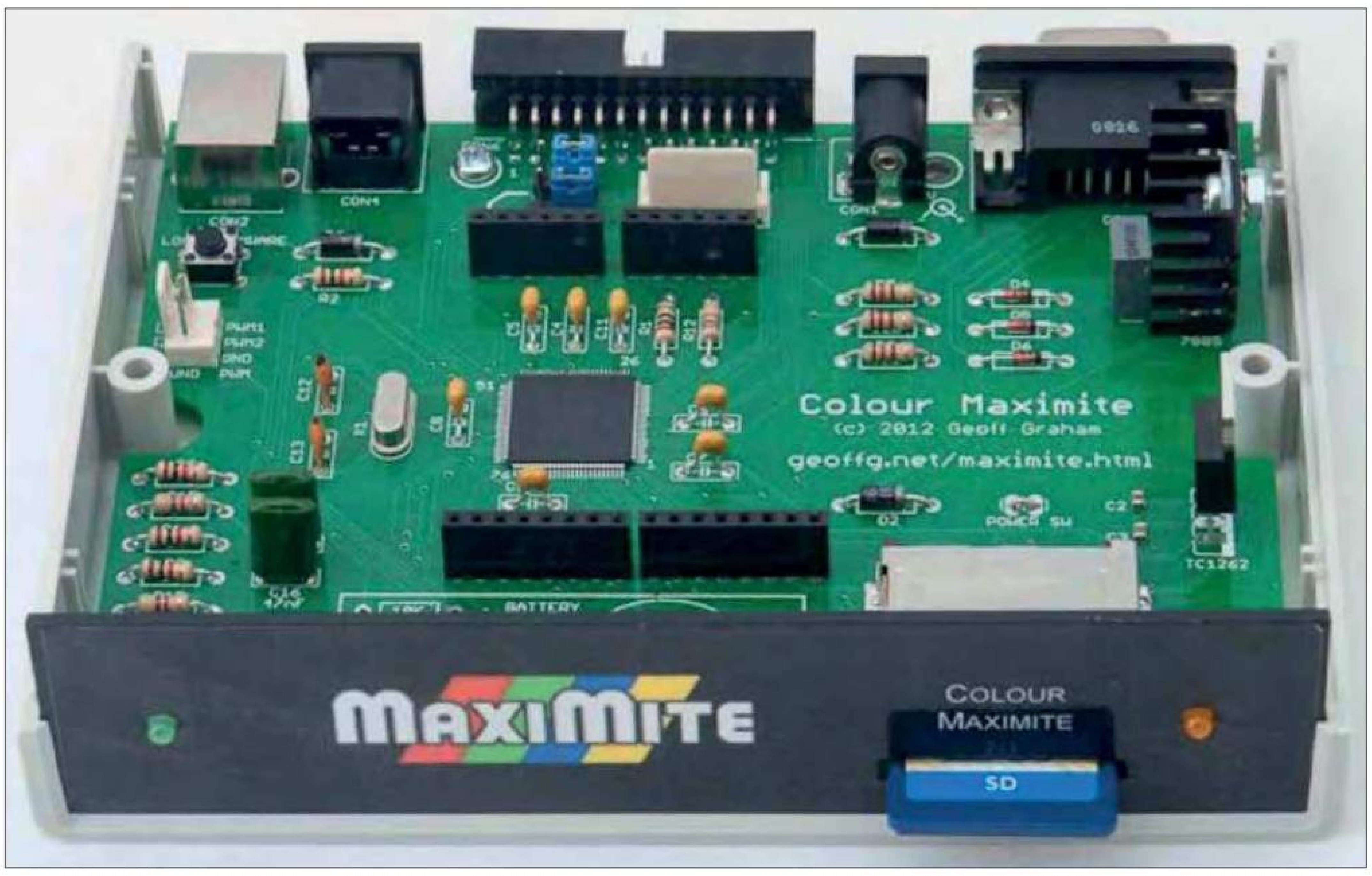


Fig.3. Colour was added to the *Maximite* in September 2012 along with several other additional features including stereo sound, Arduino Shield compatibility and an RTC option.

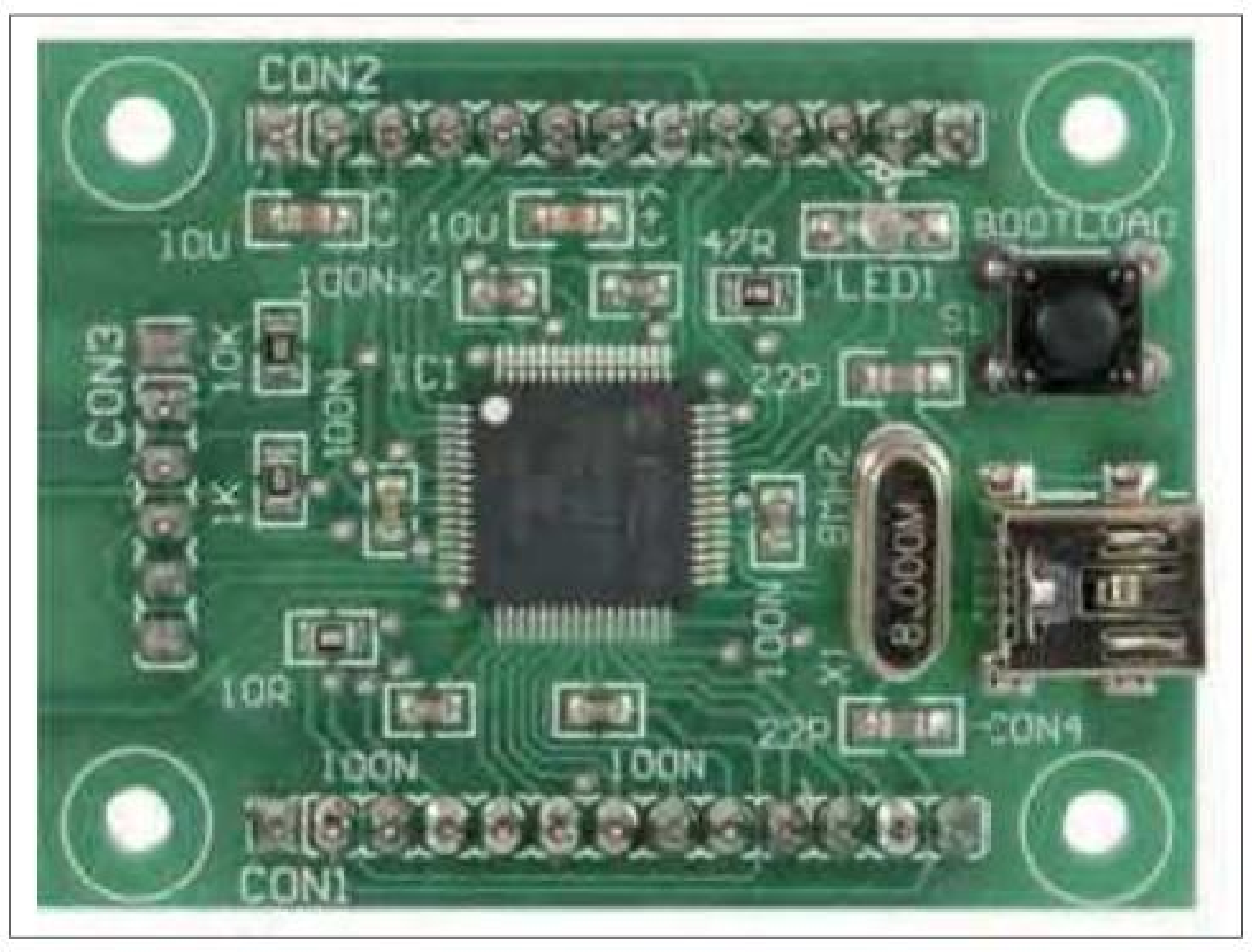


Fig.2. The *Mini Maximite Computer* was released in November 2011. It can be regarded as an embedded-controller version of the *Maximite Computer* (ie, a basic PCB with no SD socket, and no VGA socket).

STM32 and the CMM2

The *Maximite* was a single-chip design, so there was no way to really improve the hardware design without replacing the processor with a more powerful IC. Remember that the original PIC32 used in the *Maximite* is now well over ten years old. A decade is a long time in

G2 Features and Specification

- 480MHz Arm Cortex M7 STM32 processor (2MB Flash, 1MB internal RAM)
- 32MB additional RAM chip (program storage and video memory)
- VGA colour output (15 video modes, 240 × 216 to 1920 × 1080)
- Four colour modes (8-bit, 256 colours to 24-bit, 16 million colours)
- Built-in BASIC interpreter (with programs executed at circa 250,000 lines per second)
- Support for handling double-precision floating-point arithmetic, 64-bit integers, long variable names, and up to five-dimensional arrays (24MB variable storage)
- Seven built-in fonts, user-defined fonts, and full pixel control via graphics commands
- BMP, GIF, JPG and PNG image files can be read from the SD card, and drawn anywhere on screen (scaling and rotation possible)
- USB keyboard language support: UK/US English, French, Spanish, German, Dutch/Belgian
- Mouse support: either dual-mode mouse, or (with an additional chip) USB-only mouse
- Up to 128GB SD Card support (FAT16, FAT32 or exFAT)
- Built-in file manager (with mouse or keyboard control) to allow easy loading of programs
- Stereo sound output; music files supported: WAV, FLAC, MP3, MOD
- High-accuracy RTC (with battery back-up)
- 28 I/O pins with pinout identical to a Raspberry Pi 40-way HAT connector: digital inputs, digital outputs, UART, SPI, I^2C, one-wire, PWM
- USB type-B socket for 5V power, or for using an external Terminal program
- Built-in, full-screen, colour-coded Editor: up to 255-character line length, with copy/paste functionality, advanced search and mouse support
- Special features for game creation including multiple video layers with various levels of transparency, multiple video pages with high-speed copying, animated sprites and support for up to three Nunchuck controllers (two physical ports)
- Firmware upgrade via a single USB lead (no other hardware is required).

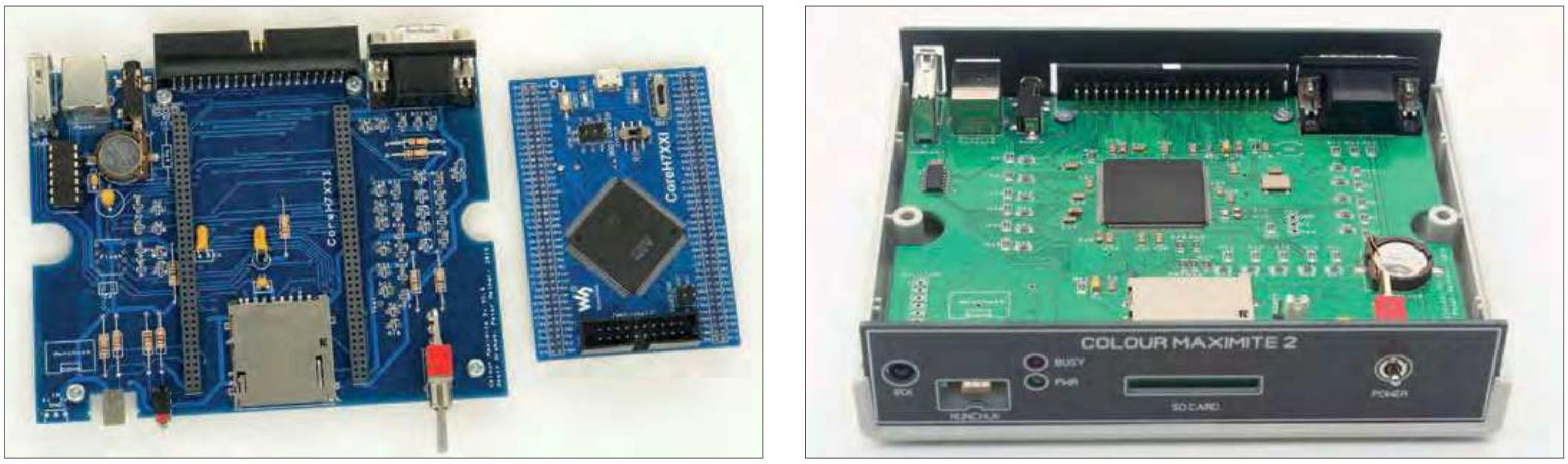


Fig.4. The *Colour Maximite 2* (*CMM2*) is based on an STM32 microprocessor. a) (left) The kit form used mainly through-hole components along with a plug-in Waveshare module which contained the STM32 chip. b) (right) The fully assembled *CMM2* used all surface-mount components soldered onto both sides of a single PCB.

terms of microprocessor progress, and the PIC32 can now be regarded as an 'ancient' device. A search for a replacement resulted in the selection of the ARM Cortex-7 STM32 processor from STMicroelectronics. It was not an easy job to migrate the MMBASIC firmware code from the PIC32 to the STM32. So, while Geoff was taking a well-earned rest, this migration task was open – step forward Peter Mather. Based in the UK, he took on the challenge, and within a relatively short time he had ported MMBASIC so that it was able to run on the STM32 processor. By using a modern processor running at 480MHz, the speed increase alone of MMBASIC on a *CMM2* was ten times that of the original *CMM*. Another immediate benefit was that there was a lot more internal memory, and this resulted in more colours being available (up to 16-bit colour), as well as providing the ability to have higher-resolution graphics (up to 1280 × 720). In addition, other graphical effects were possible, including amazingly fast screen copying and scrolling. Note that the *CMM2* also incorporated an additional 8MB RAM chip to provide even more memory required to offer some of these features. Other small additions included the ability to use a USB keyboard and to plug in a Nunchuck game controller.

The *CMM2* was released in June 2020, and featured in *Silicon Chip* a month later. It is available in kit form (Fig.4a) or as a preassembled unit (Fig.4b) from **micromite.org**

CMM2 G2

The very latest *Maximite*, the *CMM2 G2* (or simply the *G2*) can be seen in Fig.5. It has an impressive specification (see the *Features* box). However, it must be made clear that the *G2* is not a replacement for either the Micromite or the *CMM2*. The Micromite is a fantastic embedded controller, whereas the *CMM2* is an extremely powerful standalone computer, perfect for developing MMBASIC programs; not to mention that it is also capable of running some very impressive retro style games – all coded in MMBASIC of course!

The *G2* should be regarded as a *Maximite* offering the highest specification that is currently available. In fact, the *CMM2* and the *G2* both use the same STM32 processor, and even share the same firmware file, so what makes the *G2* so special?

There are three main improvements over the *CMM2*. First, the *G2* uses a bigger RAM chip, 32MB as opposed to 8MB. This allows for improved graphics capabilities (increasing the resolution to 1920 × 1080), as well as more space for much larger programs. Second, the digital-to-analogue video circuit uses eight bits per colour-channel. This results in true 24-bit colour (meaning over 16 million colours), as well as offering more levels of transparency. The third improvement is that the PCB is now 4-layer, as opposed to 2-layer. This means that all the SMDs (surface-mount devices) are mounted on the same side (the top), making it more suitable for machine assembly.

So what else does the *G2* offer in terms of hardware improvements?

- Referring to Fig.6, you can see a tiny IC to the left of the SD socket. This is a highly accurate RTC chip (DS3231) and is fitted as standard in the *G2*.
- There are now two physical Nunchuck ports that are accessed on the front panel. This makes it ready for two-player games (the *CMM2* only has one port on the front panel).
- There is a dual USB connector on the rear panel. The top USB socket is for a USB keyboard, and the lower USB socket can accept a mouse with a USB connector on it. If using a dual-mode mouse (ie, a mouse that can use the PS2 protocol but via a USB connector), then it can be used without any modifications to the *G2* (apart from a couple of solder shorts). However, a USB only mouse will require the addition of an extra chip. This is mounted near the upper-left corner of the PCB – you can see the location for it (IC5) in Fig.6. More on this next month.

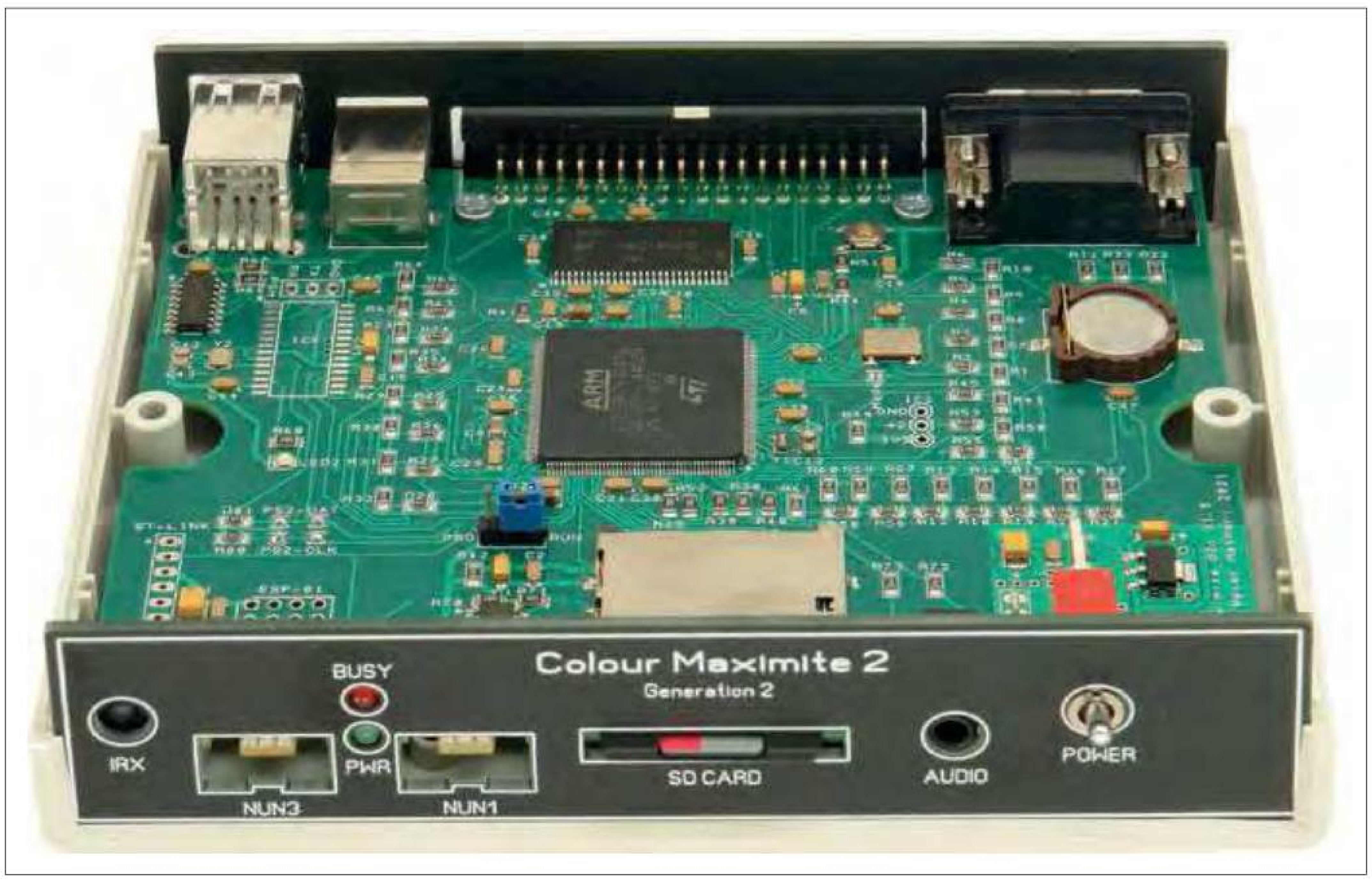


Fig.5. The *G2* uses a 4-layer PCB with all SMD components mounted on the top side. It uses the same style case as the original *Colour Maximite* and *CMM2*; however, note that the *G2* adds an additional built-in Nunchuck port.

Table 1: The four *Maximite* variants compared

Feature	**Monochrome**	**CMM**	**CMM2**	**CMM2 G2**
Processor	PIC32MX795	PIC32MX795	ARM Cortex M7 STM32	ARM Cortex M7 STM32
Speed	80MHz	80MHz	400 / 480MHz	400 / 480MHz
Built-in memory (RAM/Flash)	128KB / –	128KB / –	1MB / 2MB	1MB / 2MB
Additional onboard RAM	–	–	8MB	32MB
Max number of colours	Monochrome	8	65,536 (16-bit)	16 million (24-bit)
Max resolution	480 × 432	480 × 432	1280 × 720	1920 × 1080
Video modes	2	4	14	15
Transparency levels	–	–	16	256
Fonts	1	1	7	7
Sound	Mono	Stereo	Stereo	Stereo
Sound files	MOD	MOD	WAV, FLAC, MP3, MOD	WAV, FLAC, MP3, MOD
RTC	–	Optional DS1307	STM32 built-in	High-accuracy DS3231
SD Card storage (max)	32GB	32GB	128GB	128GB
I/O	20	20 (ext) + 20 (int)	28	28
Nunchuck ports	–	–	1	2
Keyboard	PS2	PS2	USB (wireless)	USB (wireless)
Mouse support	–	–	PS2	PS2 / USB

- There is provision for an internal ESP8266-01 Wi-Fi module located near the lower-left corner of the PCB
- A 3-way jumper by the power switch allows the switch to have its ON position selectable as either up or down (implemented due to user feedback on the *CMM2*)

The above highlights the hardware changes that have been made over the original *CMM2* design. To open up the features that the improved hardware offers, a new version of MMBASIC has been released (v5.07.00). This version of the firmware can also be installed on the *CMM2* – it automatically detects the hardware platform it's running on and behaves accordingly. This means that if you currently have a *CMM2*, several new software features will be made available (such as mouse support, and improved screen resolution) so it is worth upgrading to this latest MMBASIC. However, when you run it on a *G2* you will have access to all the new features.

All four of the Maximite variants are compared in Table 1 above.

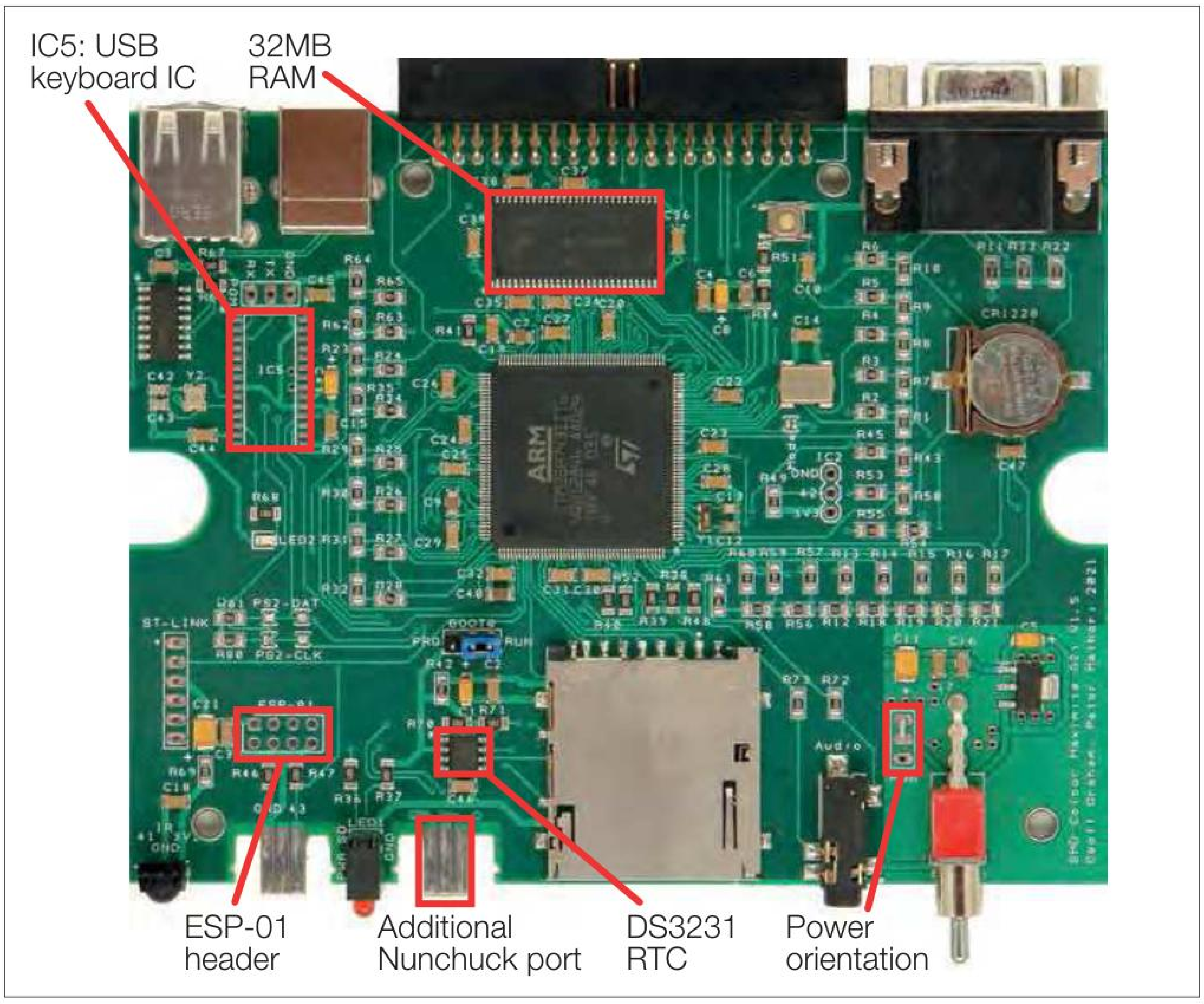


Fig.6. Additional features for the *G2*, which make it different to the *CMM2*.

Silicon shortage

At the time of writing this article, the supply of silicon has been adversely affected due to various global supply chain problems. This has greatly impacted the availability of the STM32 processor and the RAM chip; it has got to the point where global stock of the *CMM2* and *G2* are virtually non-existent. We do expect this to change, but none of the usual component suppliers can offer any guarantees of dates. Some are predicting the end of the year before they get new stock, so please be patient if you want to get your hands on a *G2*. Despite these annoying issues, we will continue next month with full assembly details.

Exploring further

This month's download from the October 2021 page of the *PE* website includes two PDF documents that will help you explore the potential of the *G2*. *The Colour Maximite 2 User Manual* and *Programming with the Colour Maximite 2* (which apply both to the *CMM2* and the *G2*) includes all the information you need to get you up and running with the *G2* computer.

Questions? Please email Phil at:
contactus@micromite.org

AUDIO OUT

By Jake Rothman

A question of balance – Part 2

Last month, we looked at the fundamental ideas behind balanced microphone preamplifier cables, including XLR connectors and suitable cable varieties. This month we'll go through the procedure of actually making a cable.

Making your own – why do it?

You might wonder why bother going to the trouble of making your own – surely just buying one would be simpler. First, you gain the satisfaction, knowledge and self-sufficiency that comes from making (and repairing) things yourself. Second, you can do a really good long-lasting job; for example, using proper leaded 60/40 solder that doesn't crack. In the UK, all commercial cables must be made with that awful lead-free, tin-based solder. Last, although ready-made Star Quad microphone cables are available, they cost around £25 – you can make one for a lot less.

Strip tease

The conductor wires are best stripped with a proper multi-toothed stripper, such as the AB Mk 1 that can get to the short leads without pulling too much. Fig.18 shows the tool in action.

The thick outer sheath or jacket of the cable can usually be 'nibbled' around with side cutters, as shown in Fig.19. The trick here is not to go in too far. If the braid or inner conductors get nicked you have to snip it off and start again. You cut around 80% of the thickness down and bend it until the final uncut lower portion breaks. Pulling the sheath away outwards from the cable while cutting also helps. These tricks require practice, and it gives an unsightly, ragged edge. Single-sided razor blades and scalpels can be used, which – with practice – can give good results, although I don't like this approach, electronics dribbled with blood is unsavoury.

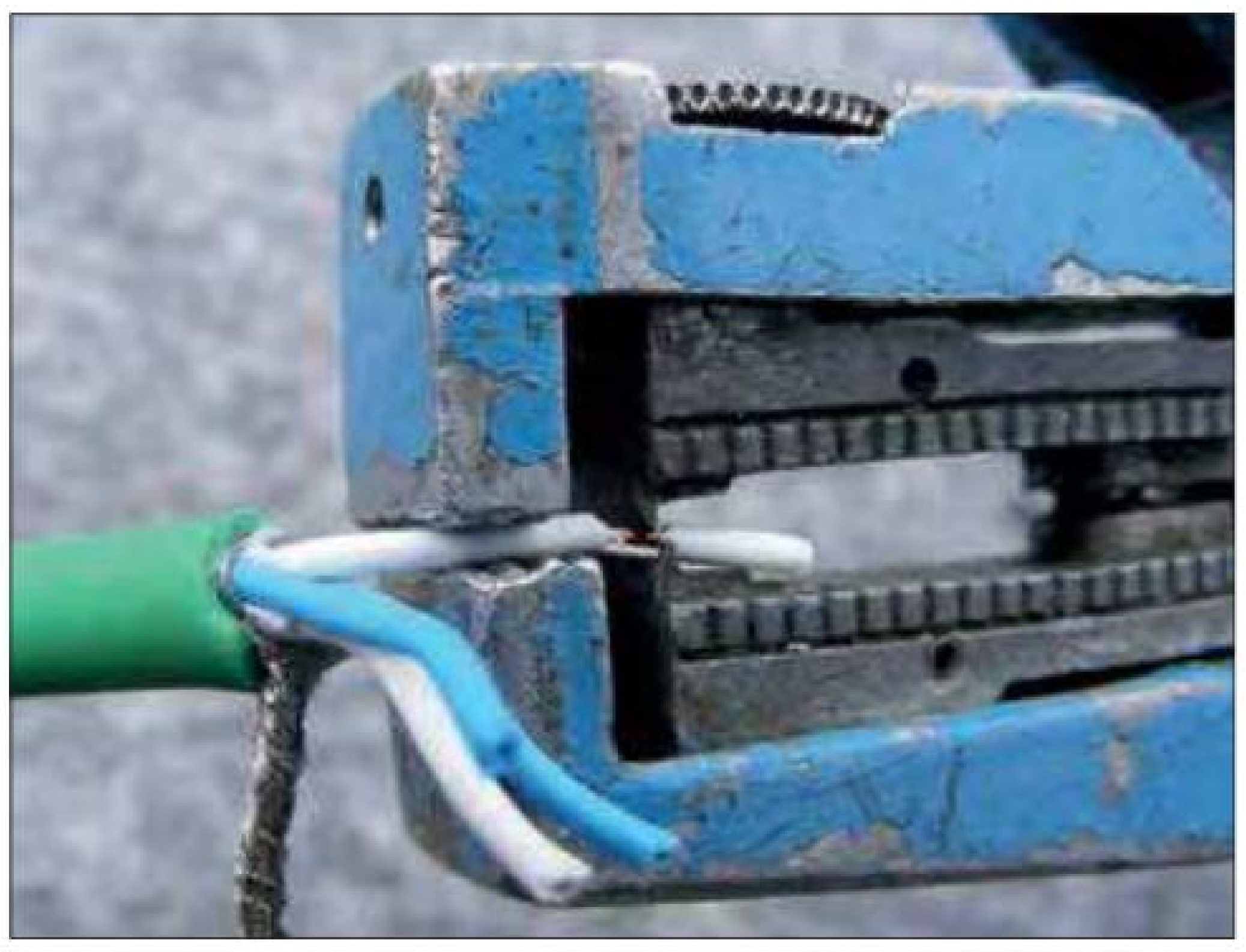


Fig.18. Stripping the signal conductor wires needs a decent wire stripper that can deal with the short length available. I've used this AB Mk 1 since 1983. They are still available from Grove Sales.

Professional stripping tools are available for coaxial leads (Fig.20) that do a better job, but some don't work. All engineers have a drawer full of tools bought and then abandoned. My drawer seems to have more useless wire cutters/strippers/benders than any other tools. There is a low-cost blue plastic squeeze blade tool that can give good results (shown in Fig.21) for occasional use. I use the MK02 swivel blade tool from **Ripley-Tools.com** – shown in Fig.22. You set the depth of the blade and press it into the insulation. Then you spin it round to do the cut. The button is then pressed to rotate the blade 90 degrees to do a slit along the sheath as you pull it off. It's worth getting one if you do lots of leads.

Teething troubles

Do not use your teeth for stripping! I've had to spend £3000 on bridge work and I've a friend who had an electric shock so bad he was flung into a filing cabinet that still bares a massive dent. I fantasise that if I ever need dentures, I'll have an

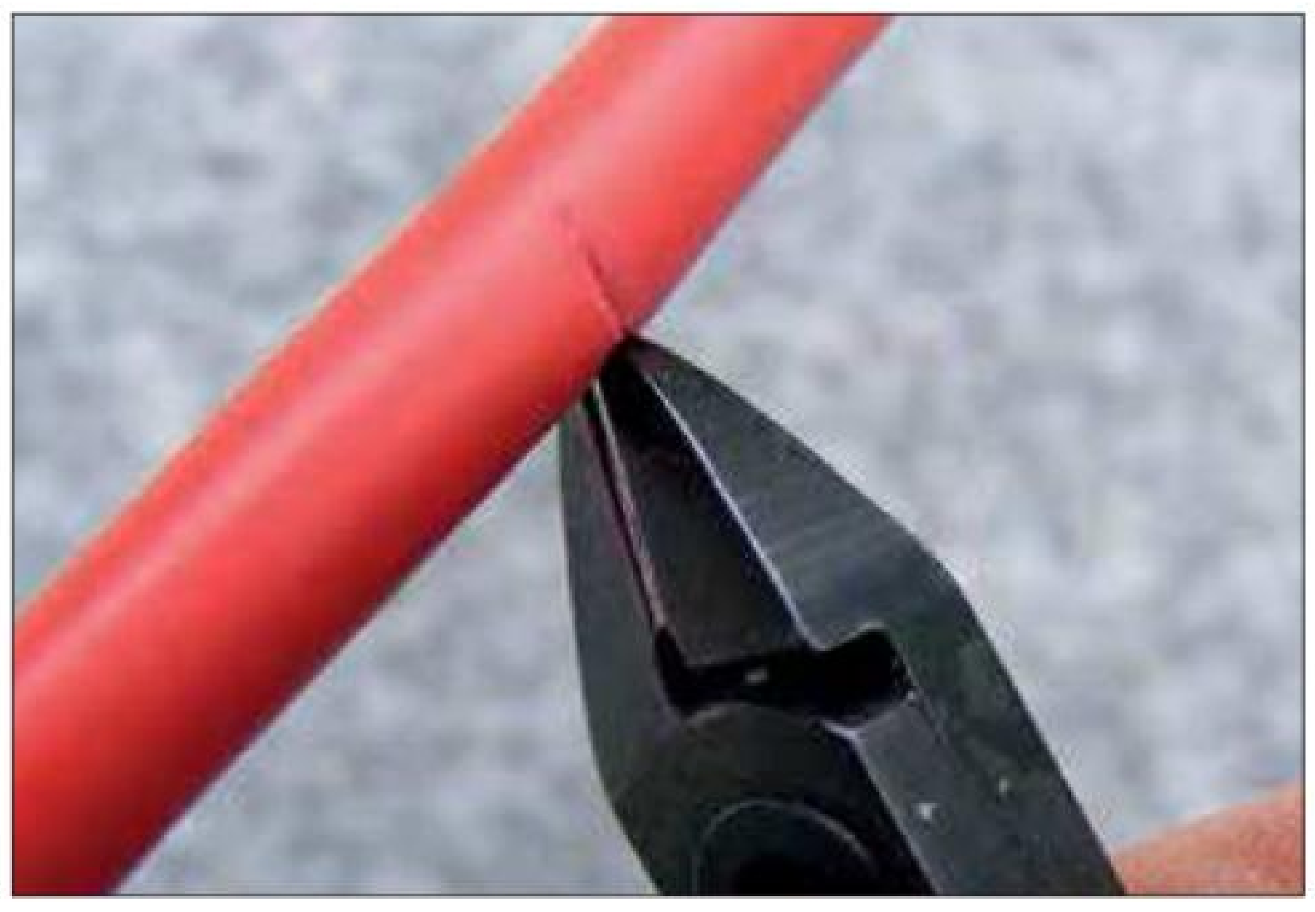


Fig.19. Side cutters can be used to 'nibble' the outer jacket to strip it – fine for small batches of cables.

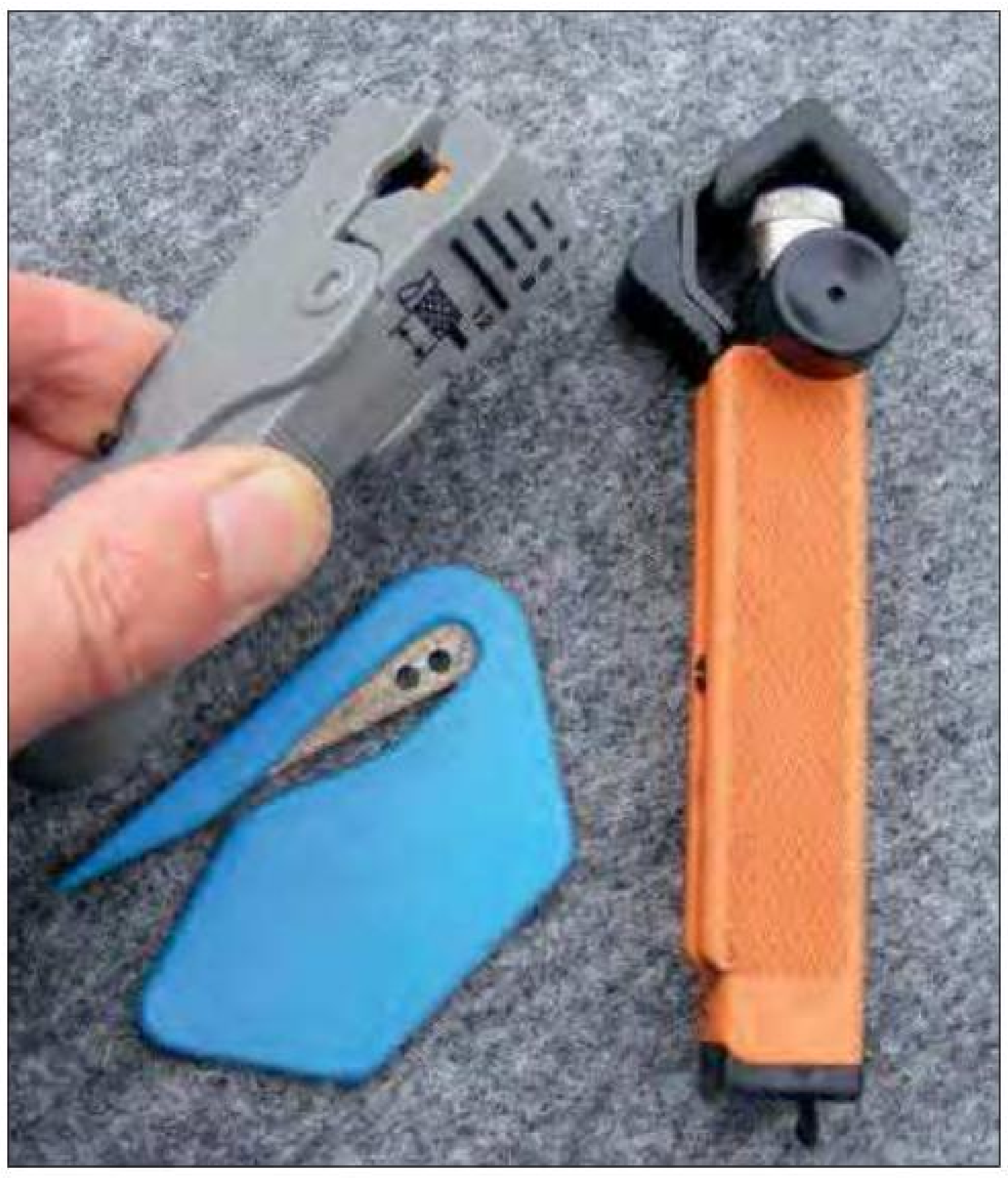


Fig.20. A selection of jacket-stripping tools.

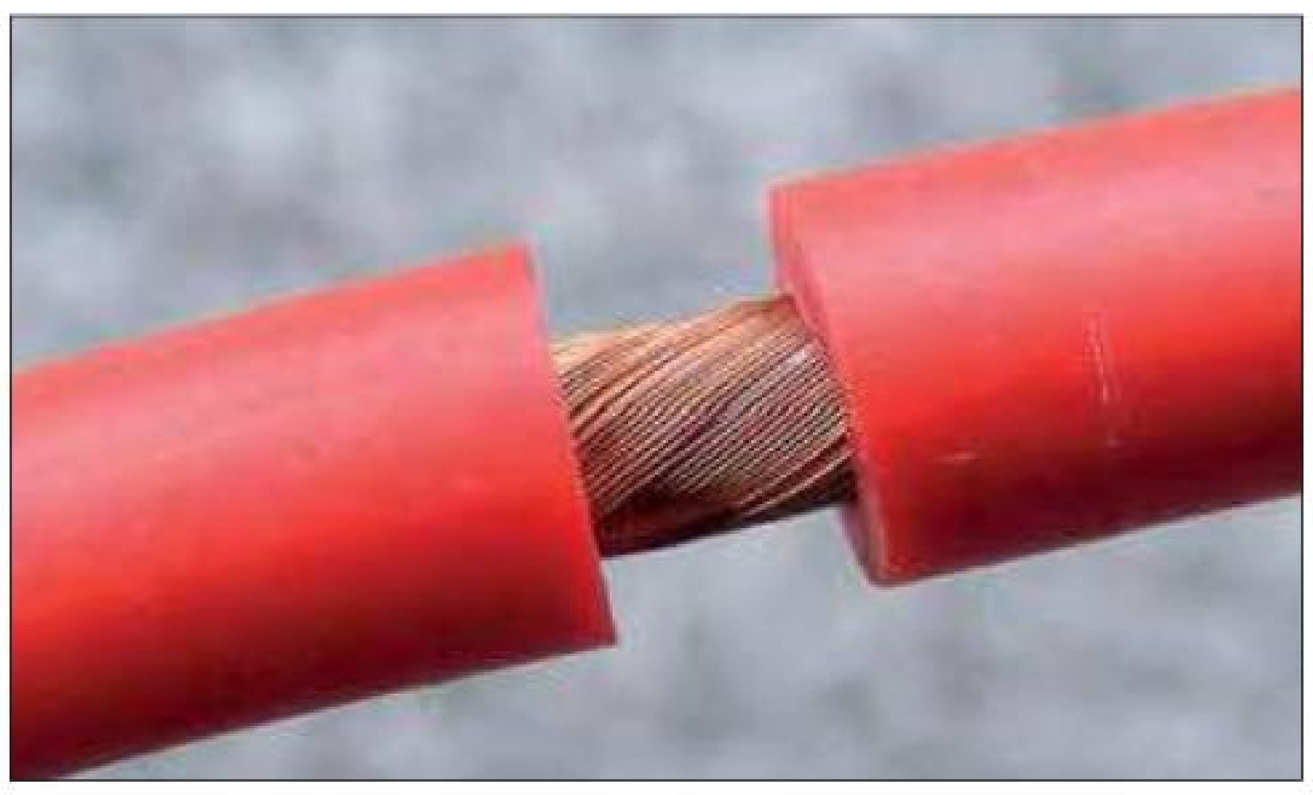


Fig.21. A surprisingly clean jacket cut done with the cheap blue blade tool in Fig.20.

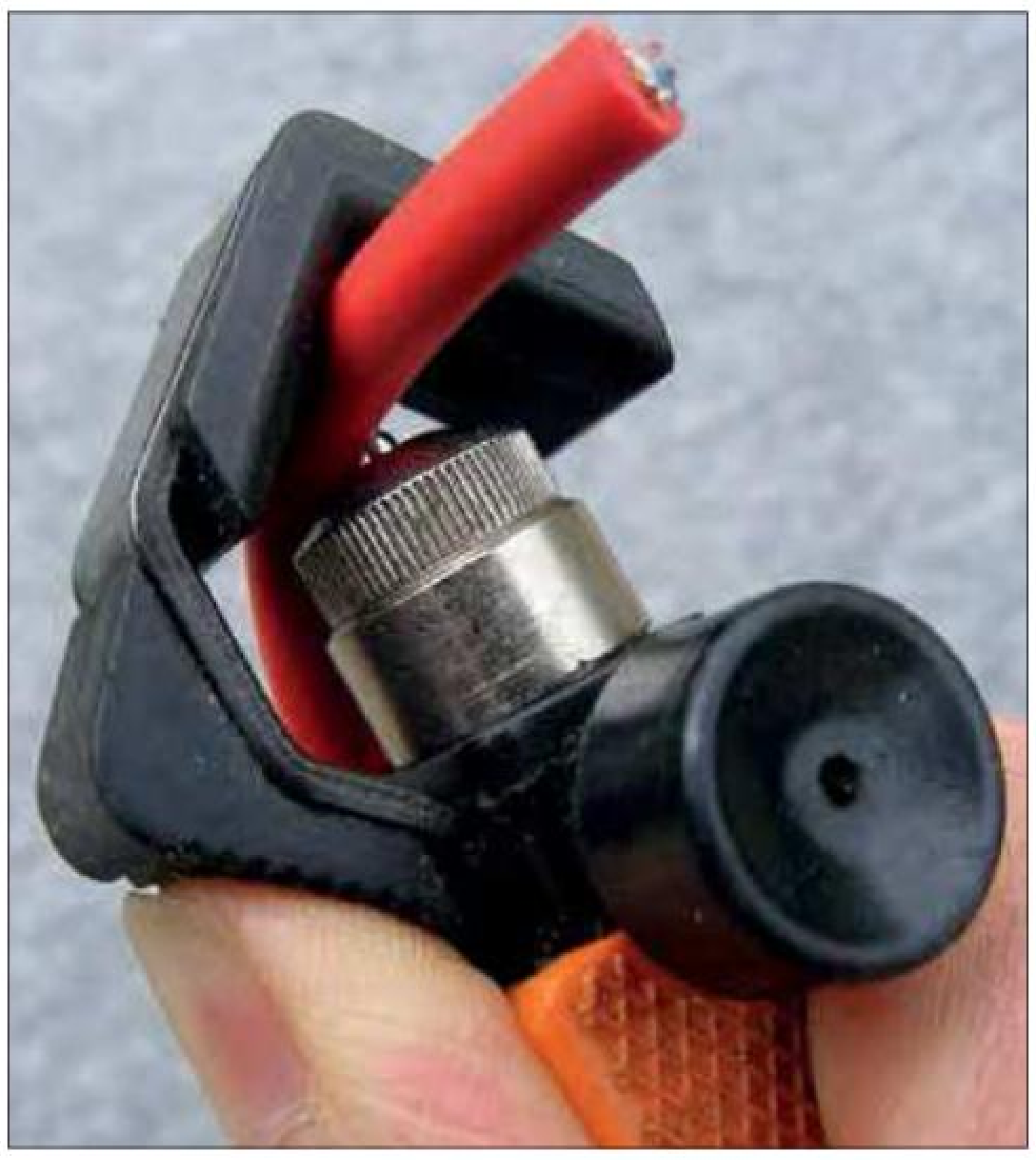


Fig.22. The rotatable blade of the MK02 tool can just be seen. The circular bush enables the depth of cut to be set and the black button is the blade rotate.

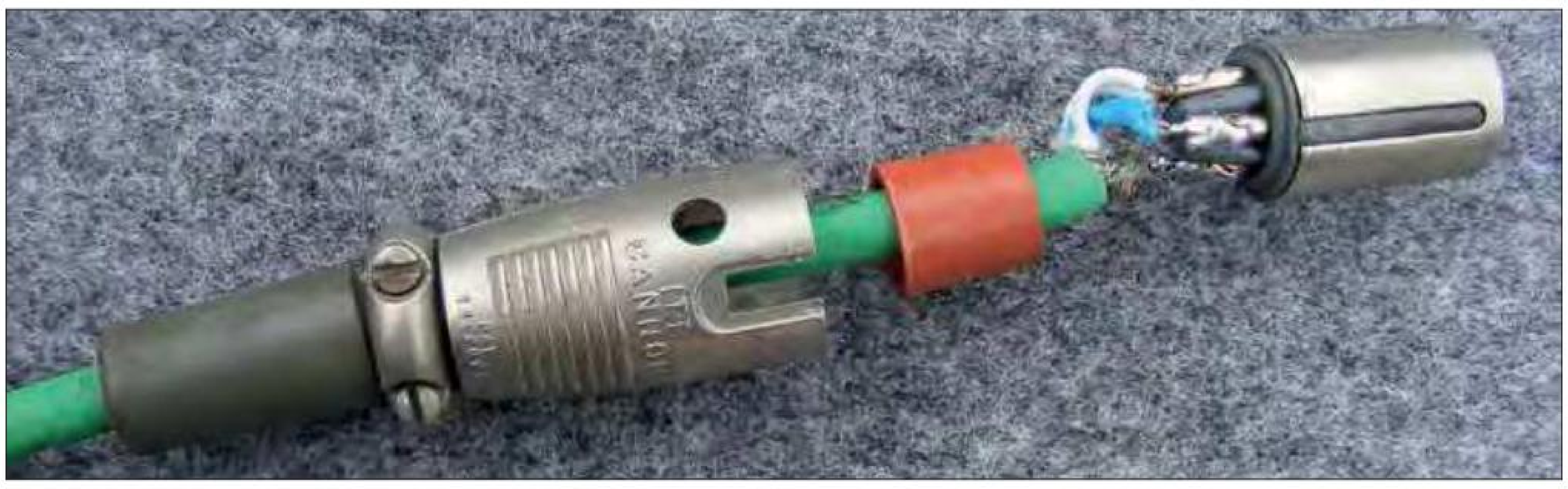


Fig.23. The wireman's mantra: slide on all required bits onto the cable *before* soldering.

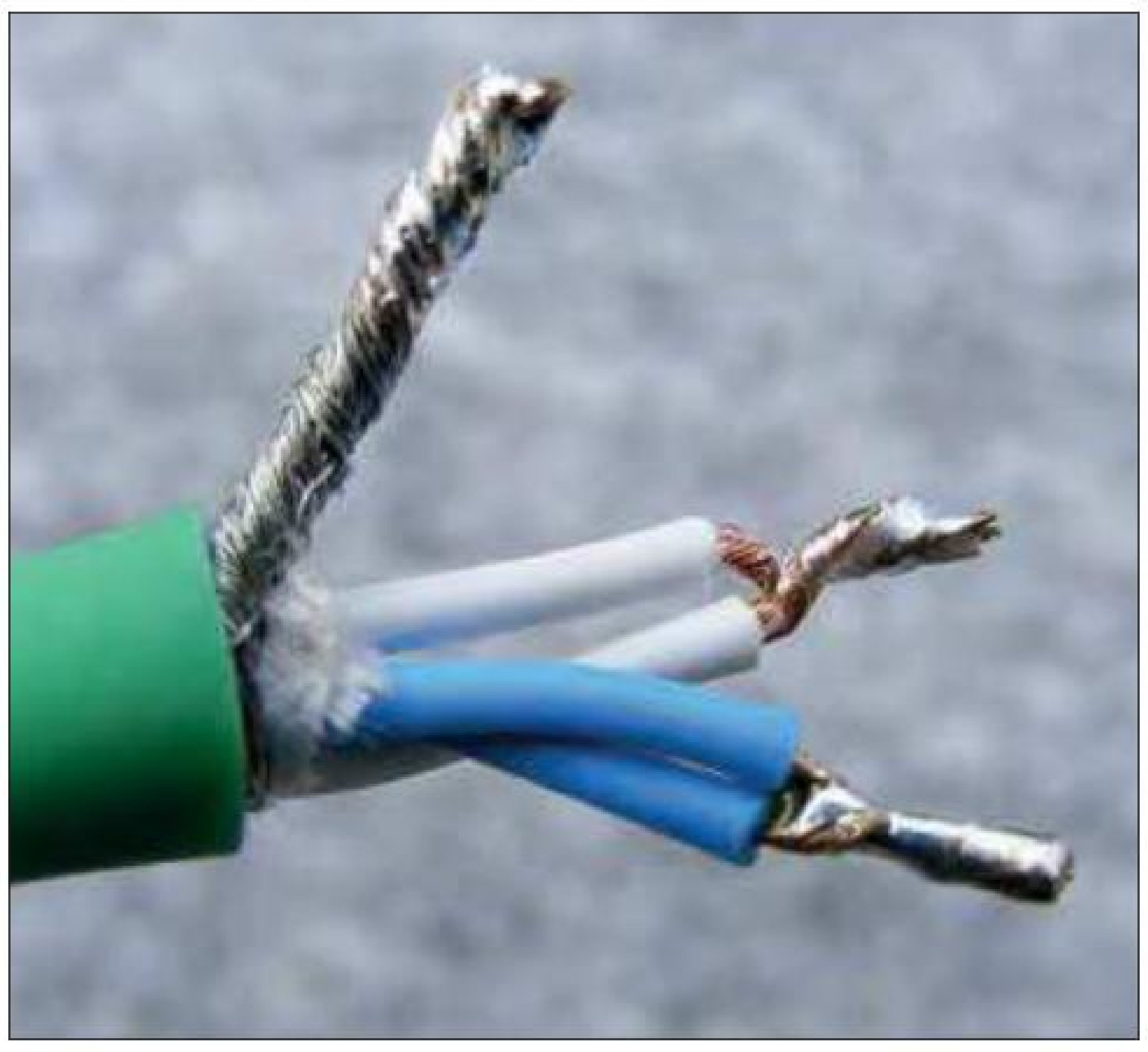


Fig.24. Twist and tin the wires, then cut to length. A properly prepared cable termination using Star Quad.

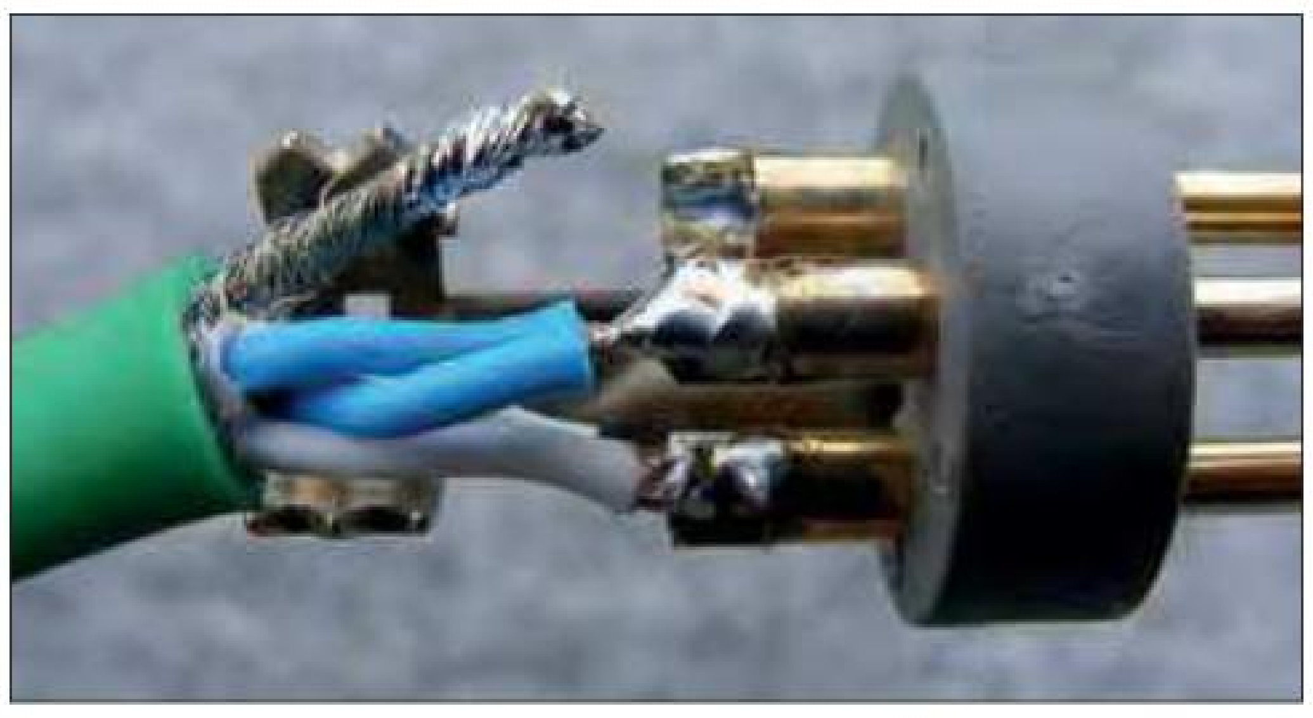


Fig.25. Solder the hot conductor wire by heating a bucket filled with solder. Then put in the cold conductor and solder. Finally, solder the shorter screen by pushing it in leaving a 'loop' in the conductor wires.

insulated multi-gauge titanium stripping set, along the lines of 'Jaws' in *James Bond* films.

Slide it on

There is nothing more annoying when making cables than doing a beautiful soldering job and then finding that you've forgotten to put the case, cable clamp or insulation sleeve onto the cable first (Fig.23). I still do it occasionally.

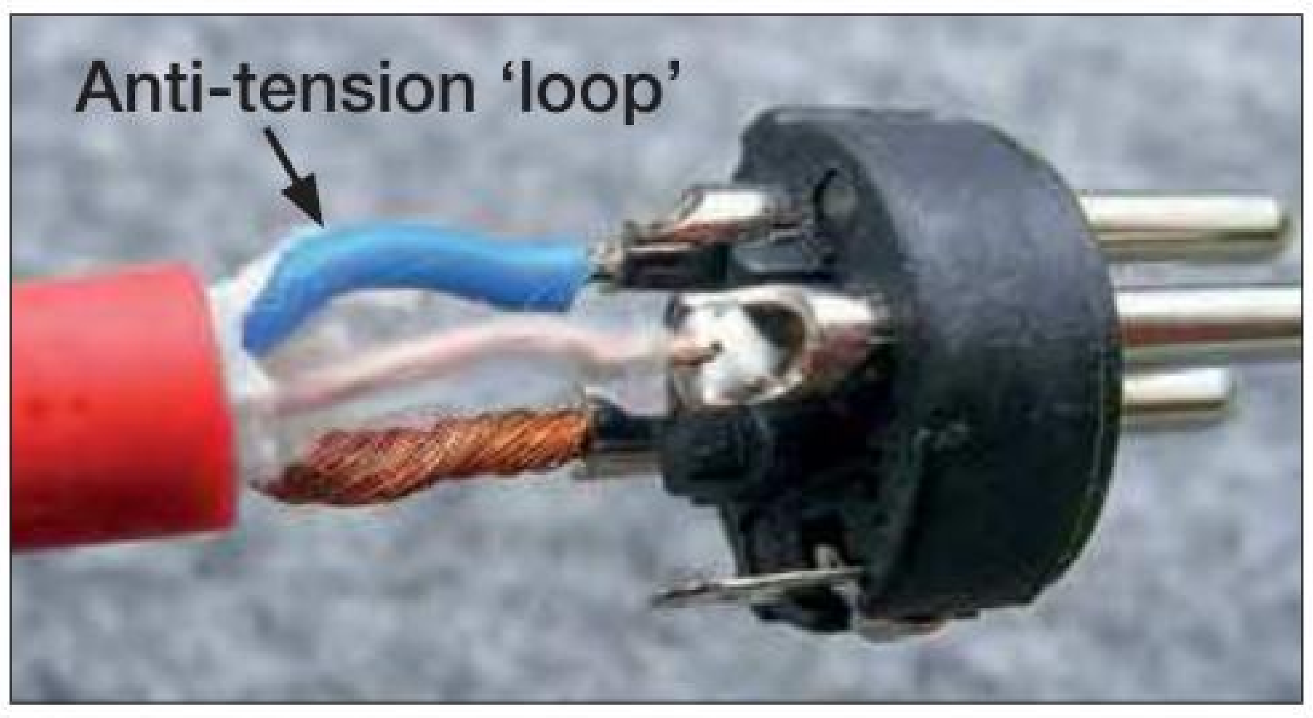


Fig.26. How a correctly soldered insert should look using standard lap-screened microphone cable.

Tinning

It's always a good idea to twist and tin the conductors before soldering. High-quality cables have tinned conductors and look silvery. Cheaper cables are untinned and have the characteristic pink bare copper colour. It is essential to tin these cables first. Twisting and tinning before soldering avoids random whiskers of wire that can cause intermittent crackling during the first and last time the *Fat Lady sings*. Always cut the conductors to length *after* tinning, to allow for insulation shrink-back.

Lead length

For XLR connectors, the conductor leads should be about 13mm long, including 3mm of tinned portion. The bare screen lead needs to be shorter, at 10mm long. It is always better to twist and tin a longer portion before cutting to the 3mm required. This is so you can hold it with your fingers and to obtain a proper circular cross section. Twisted wires usually go a bit splayed at the end of the twist, which can inhibit insertion (Fig.24).

For mains power leads, the earth lead must be made the longest so that it is the last to come off if the lead is strained. Obviously, this is necessary for safety. However, with audio leads the opposite applies. If the earth lead comes off first, all you get is extra noise. This is preferable to loss of signal from broken signal conductors in a live situation; and it's easier to trace. Also, the braided or lapped shield conductor is thicker and stronger than the signal conductors. Because the signal conductor wires are more flexible, these are soldered first and the screen soldered last with a pushing action, as shown in Fig.25. The finished result is shown in Fig.26.

Solder buckets

On some XLR connectors the silver-plated solder buckets can become oxidised if stored near contaminants such as diesel fumes or other sulphurous smoke. Use a small brass brush or needle file to clean them. I fill them with solder and knock it out while still molten to tin them (Fig.27). Use a big iron, such as a 60W Weller; a little 15W Antex iron used for PCBs won't cut it for high thermal-capacity XLR pins. Wear eye protection, since it's mostly desoldering that results in flying solder. Fig.28 shows the result of not tinning things properly and using an iron that's got insufficient heat capacity. The wires are just held on by flux.

One of the thing I like about XLRs is that the pin numbers are always marked. If you can't see them, you need a magnifying glass. Some XLRs have an extra tag for earthing the metal case to provide RF screening. This can be connected to pin 1, as shown in Fig.29. In rare cases where no connection is wanted between metal work and pin 1 (which incorrectly may be signal earth

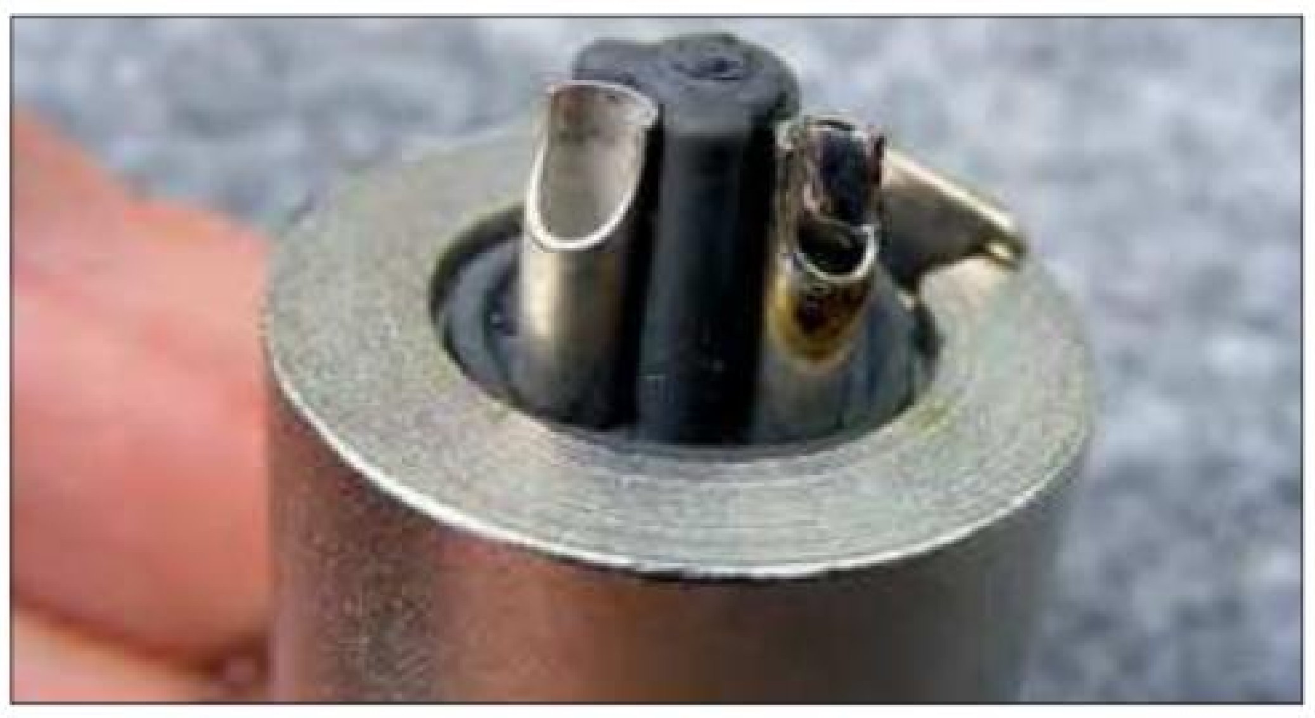


Fig.27. Clean and tin oxidised buckets. Use 3% activated rosin 60/40 tin/lead solder for top results. No-clean fluxes and European tin-based unleaded solders are no good. Best of all is Multicore low melting point (LMP) 2% silver-loaded 62/36/2 solder.

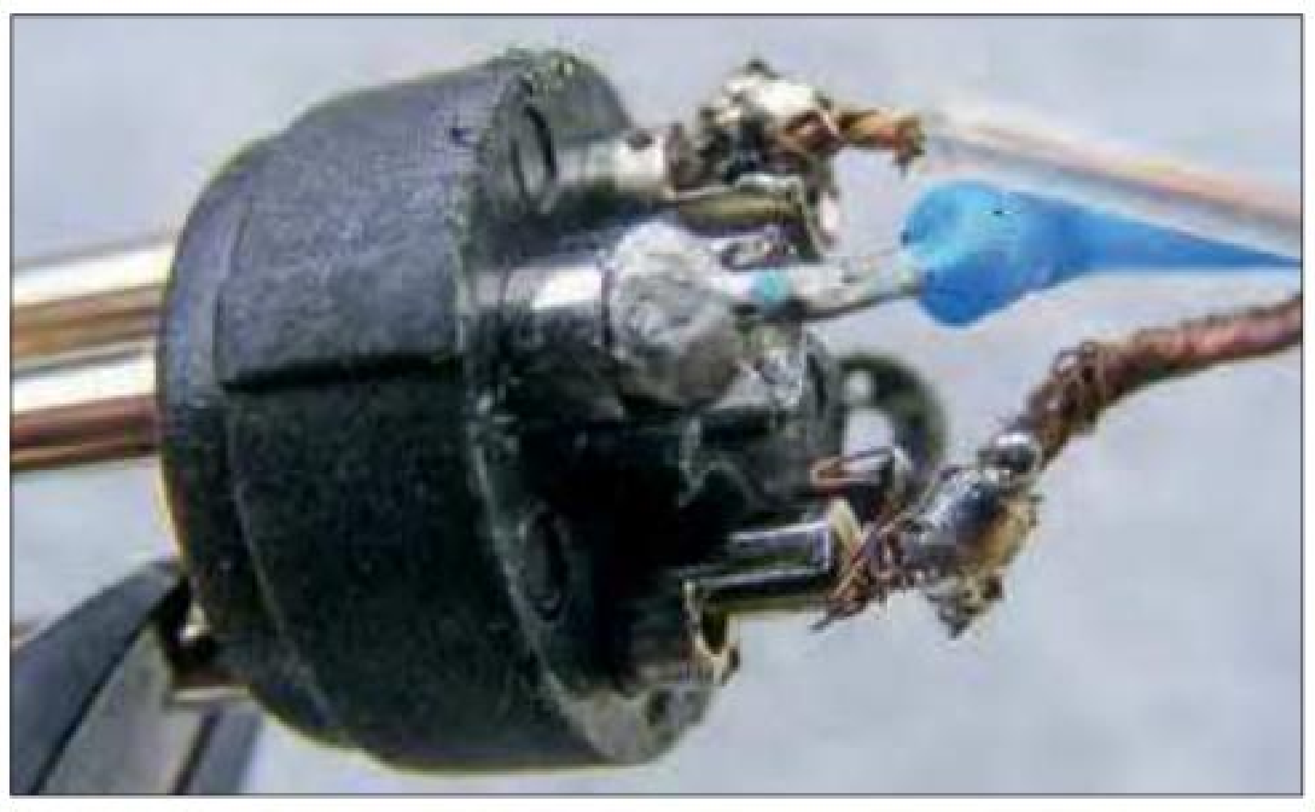


Fig.28. How not to do it. Everything that could go wrong has gone wrong: insulation melt back, non-wetted joints, grey unleaded solder ball-up and shorts due to loose strands. Poor student – grade F.

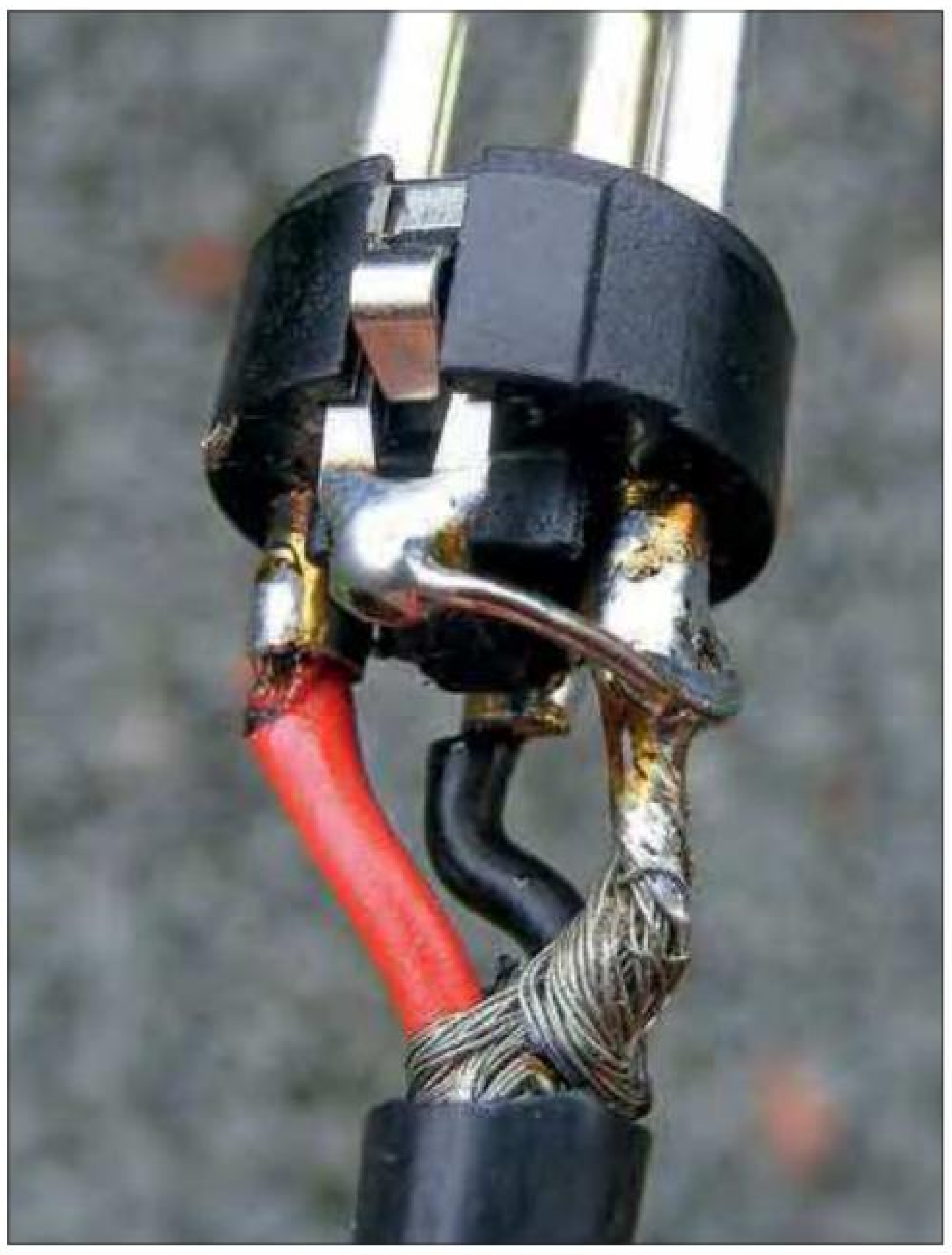


Fig.29. It's not normally needed, but sometimes the case of an XLR can be earthed to pin 1 via a tag.

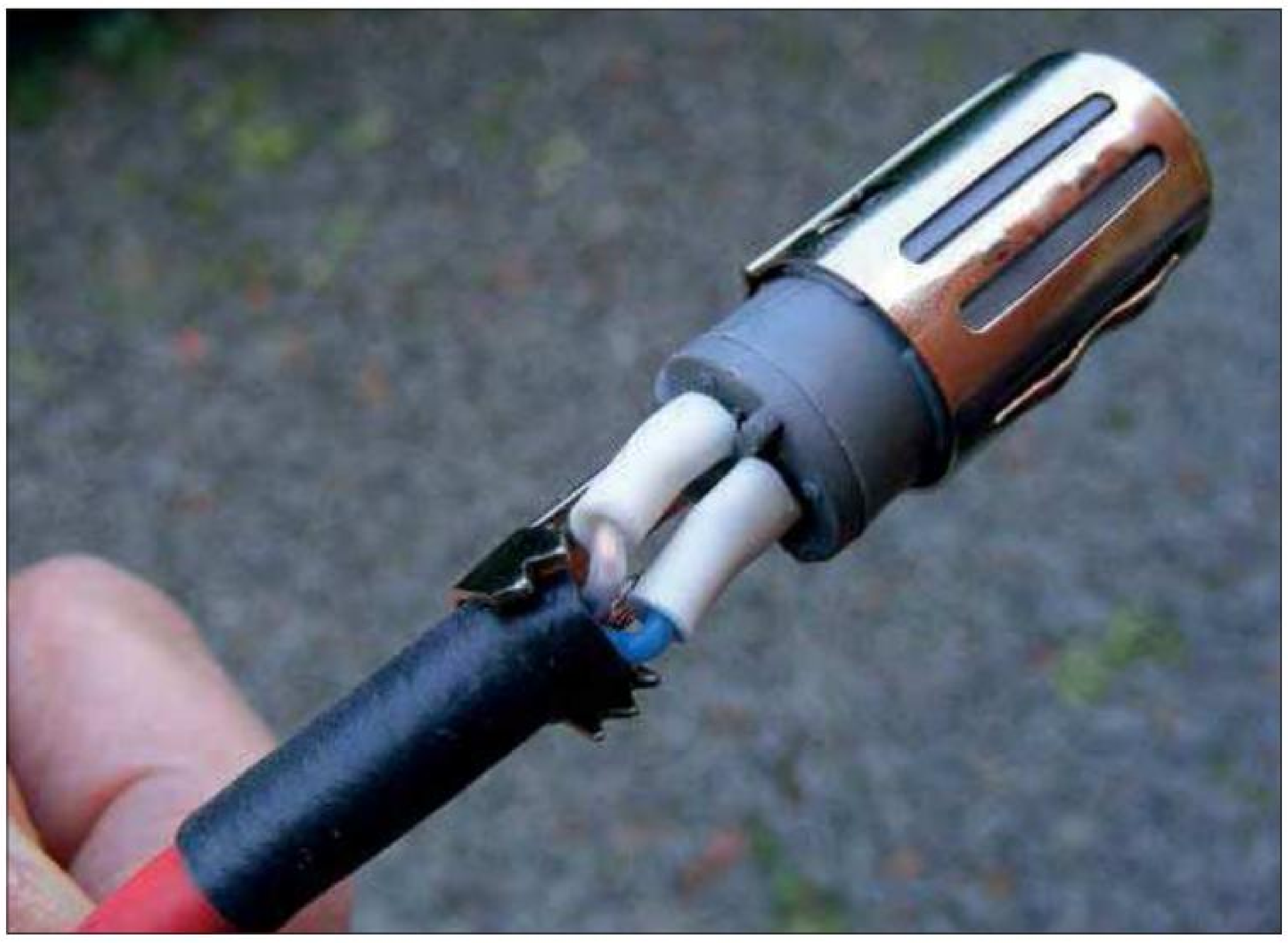


Fig.30. Silicone sleeving used to prevent shorts from loose strands. This is shown before cable clamping. If you solder well, it's not necessary. Sometimes it's used to hide bad joints underneath.

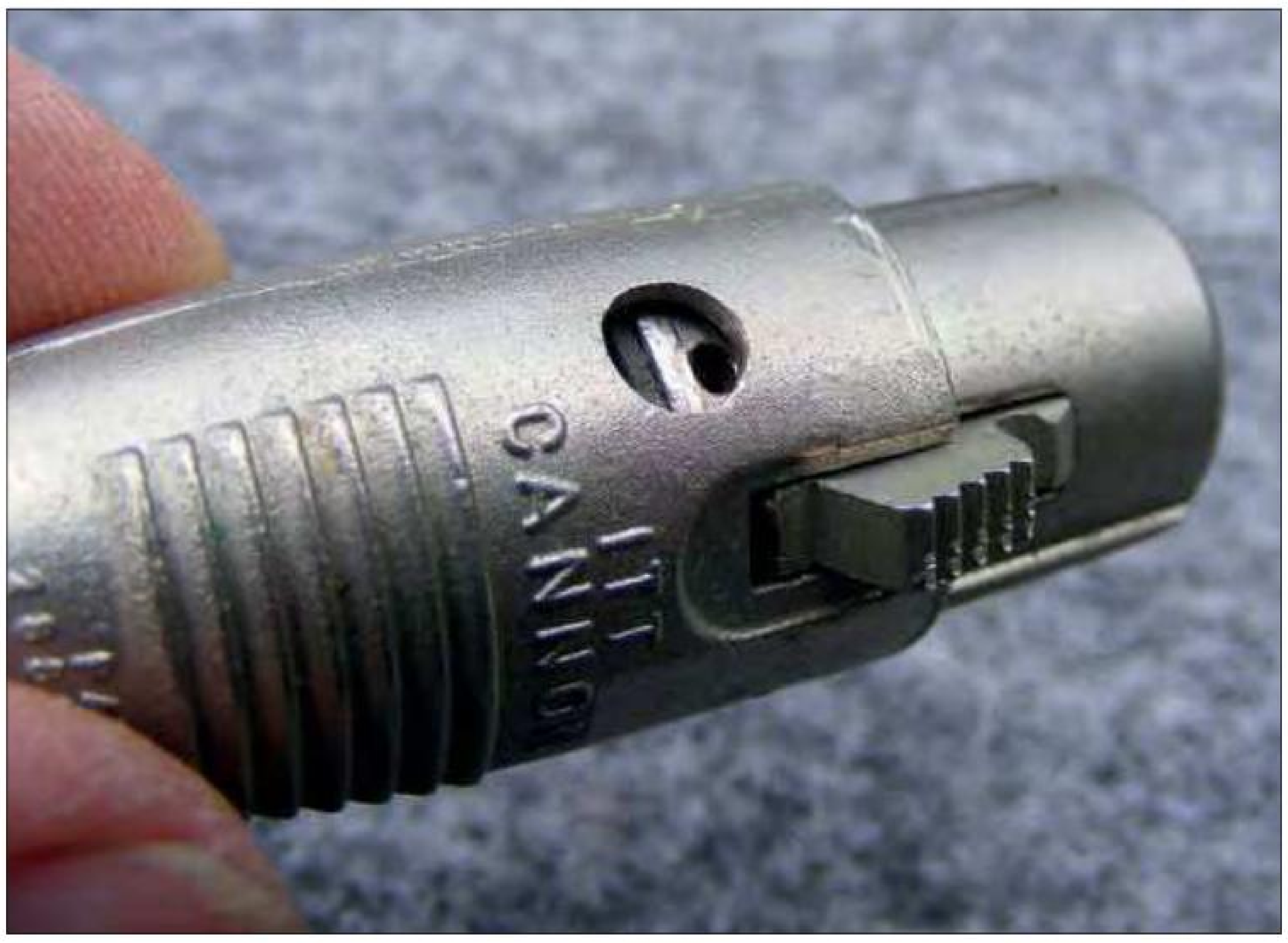


Fig.31. Tighten up the cable clamp first before pushing the XLR insert in fully (see screw hole). This ensures the signal wires are *not* tensioned and pulling against the solder.

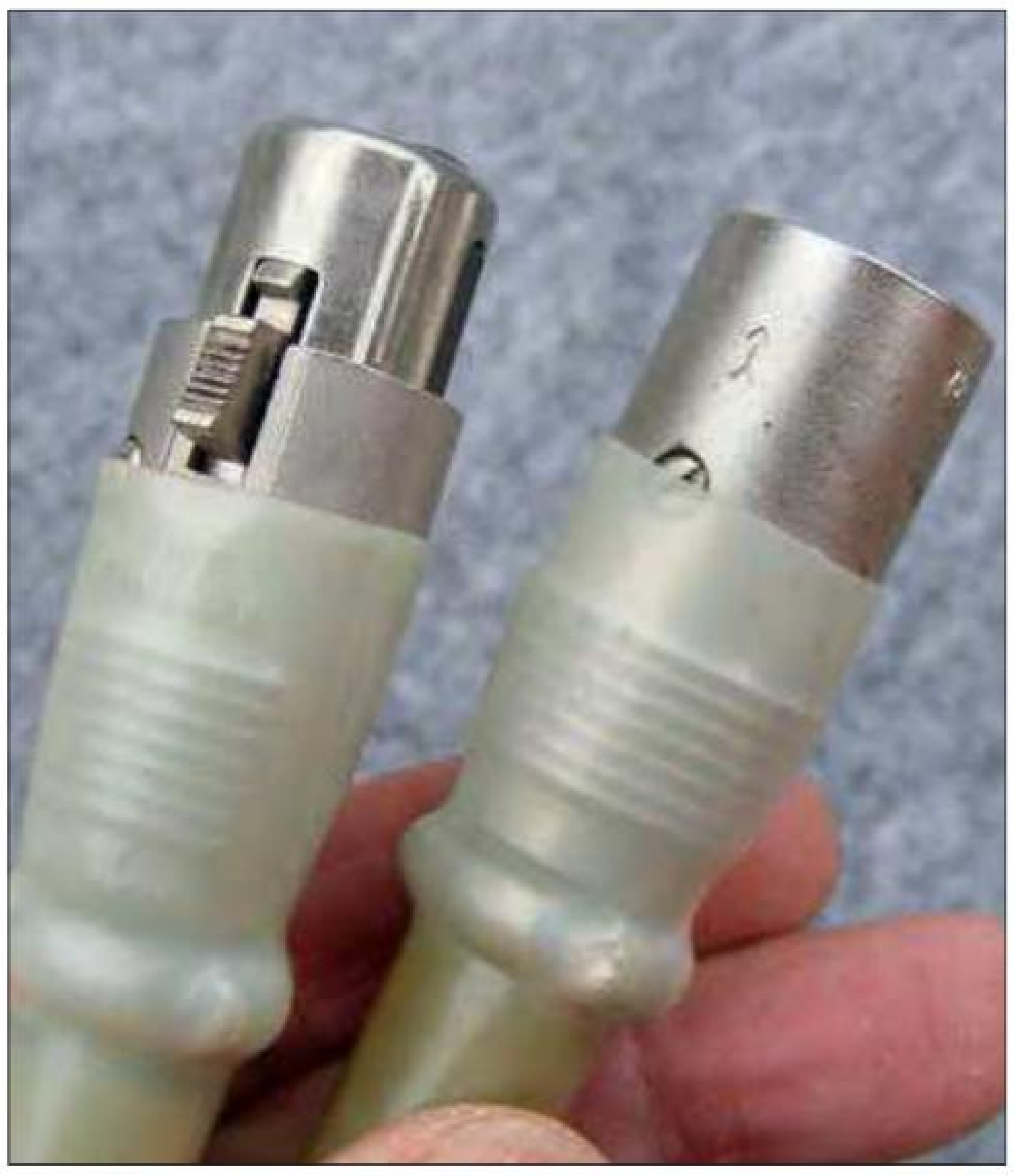


Fig.32. If you're using connectors with many screws it can be worth heat-shrinking the case to hold them in. It can also prevent the case causing shorts if dropped inside equipment.

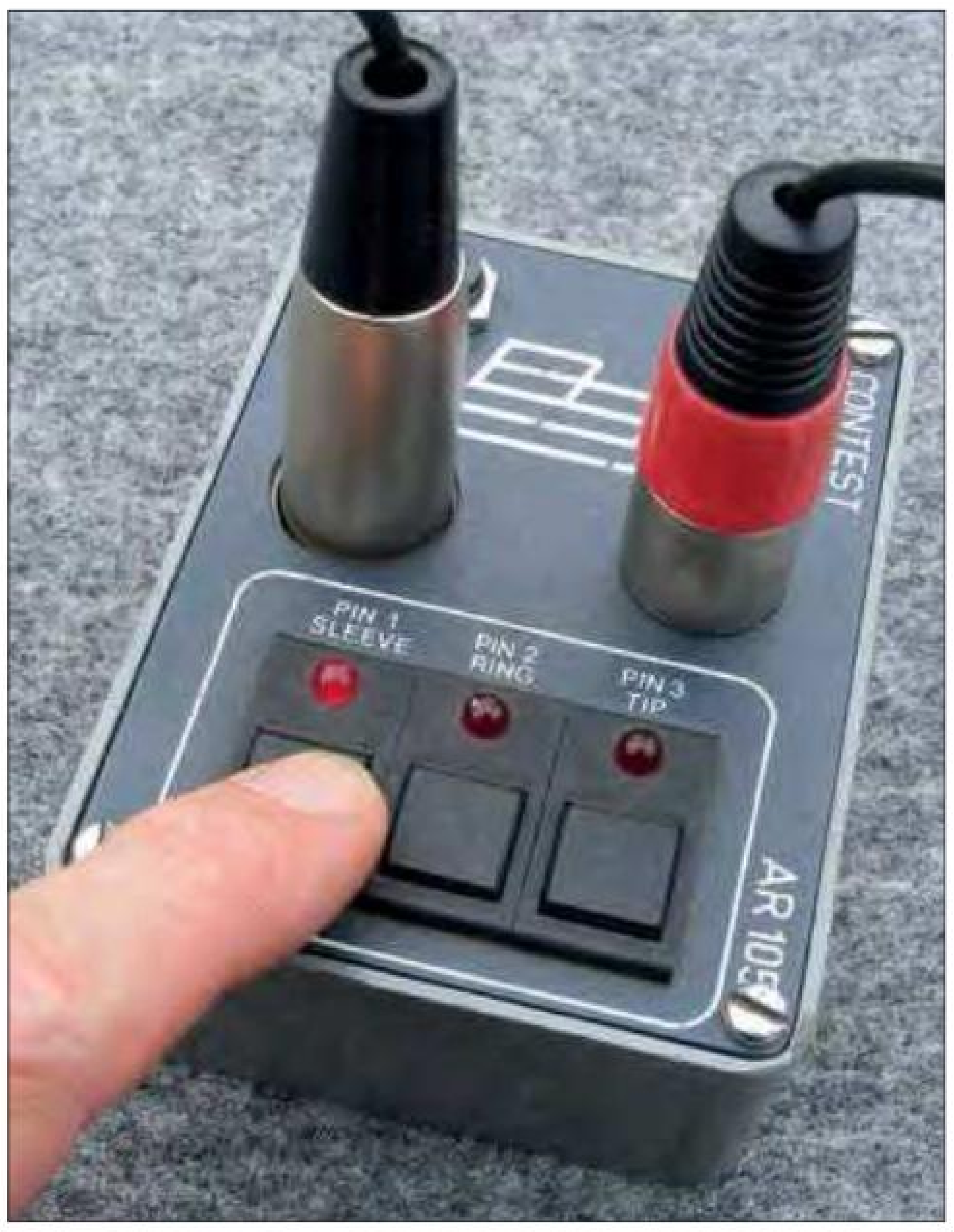


Fig.33. If you're making lots of leads then a cable tester is a sensible investment. This BSS unit is designed for XLR and TRS jack leads.

on some systems) the link may be left off. The AES recommends leaving it off since they worry about the metal case touching and earthing something it shouldn't. On my workshop test leads I prevent this by making the link with a 10nF capacitor, which provides an RF path.

Sheathing

A lot of audio technicians like to slide silicone rubber sleeves over the pins to prevent shorts, as shown in Fig.30. A bit of lubricant such as Hellerine makes this easier. Larger sleeves are often placed on the end of the cable sheath to cover loose strands from the braid and to aid clamping thin cables. If the preparation is done properly there should be no loose strands and sleeving should not be necessary.

Cable clamping

Before putting in the insert retaining screw, tighten up the cable clamp where the cable enters. The insert should be a few mm away from the screw hole before it is pushed in to meet up (Fig.31). The idea is to have a little extra slack in the system – ie, a strain-relief section in the cable. The wires should never be tight inside the case or they will break.

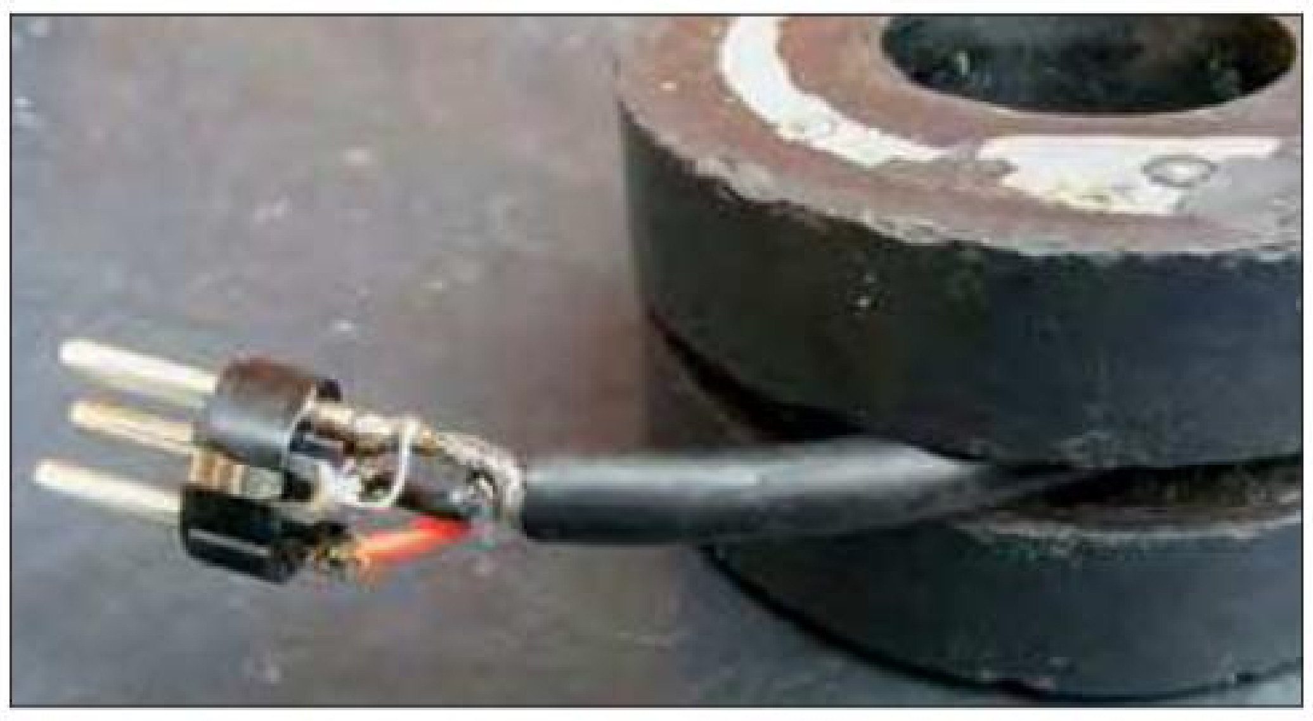


Fig.35. Old speaker magnets are a good way of holding leads while tinning and soldering. Also, I often use the tester shown in Fig.33 as a way of holding the inserts while soldering.

Locking and heat-shrinking

To avoid losing screws in Cannon XLRs I usually heat shrink them as shown in Fig.32. A dab of nail varnish is recommended to lock screws.

Latches

XLRs are latching connectors, meaning they lock into the socket with a click. To unlock them and withdraw the connector, the latch has to be depressed. This is

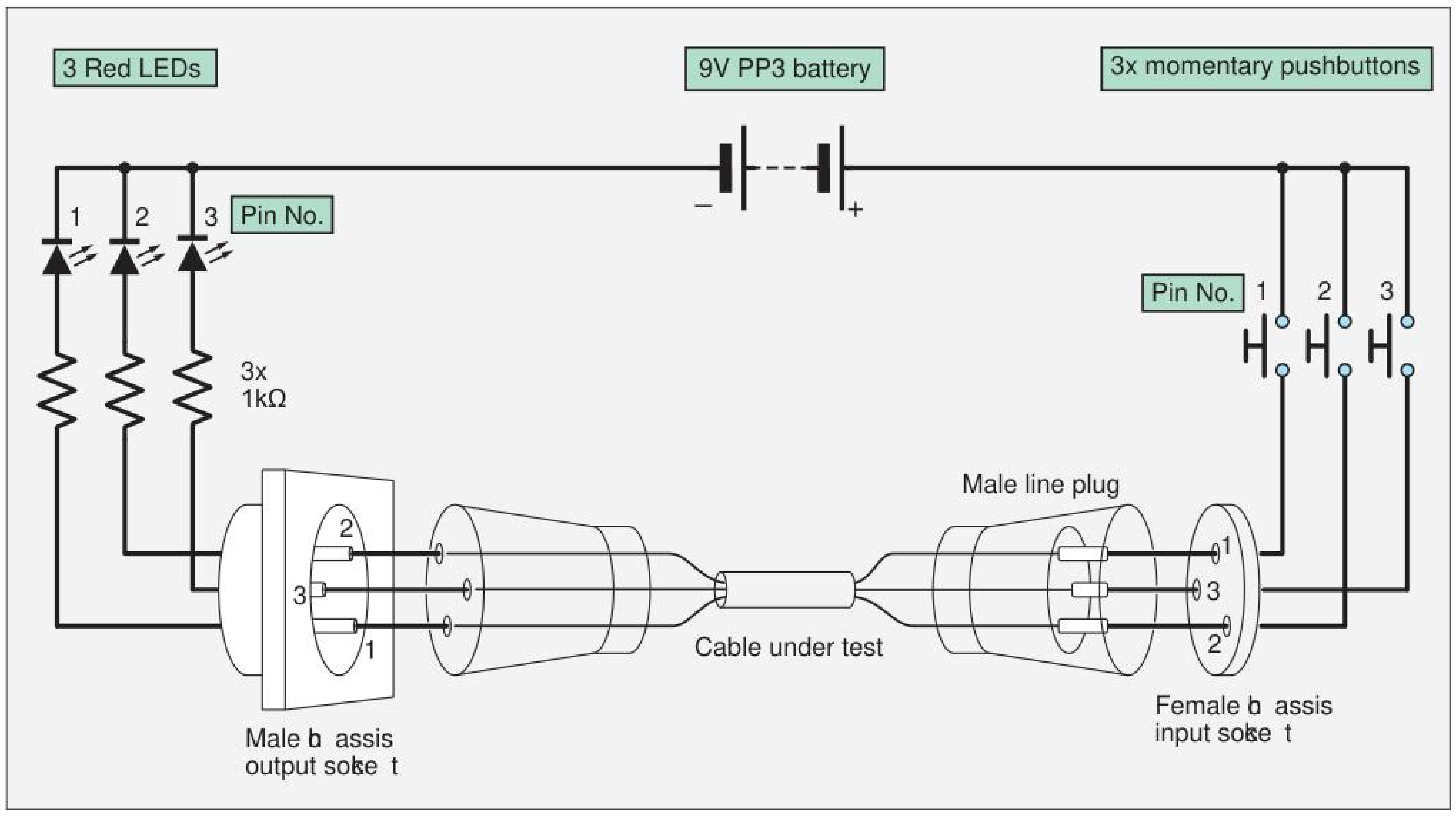


Fig.36. It's easy to make your own XLR cable tester – this circuit works well.

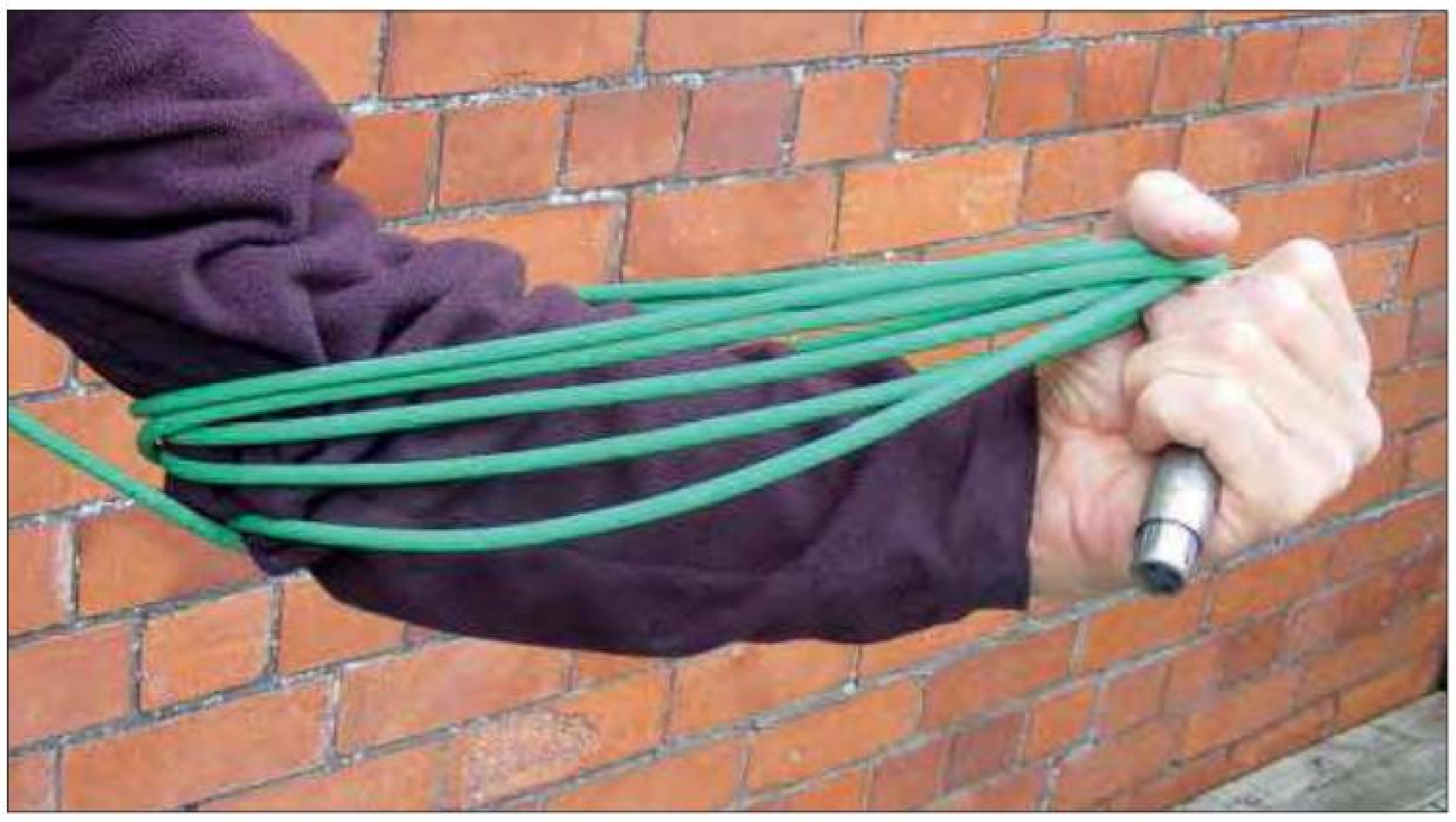


Fig.36. Don't wind cables up like this, it strains the conductors.

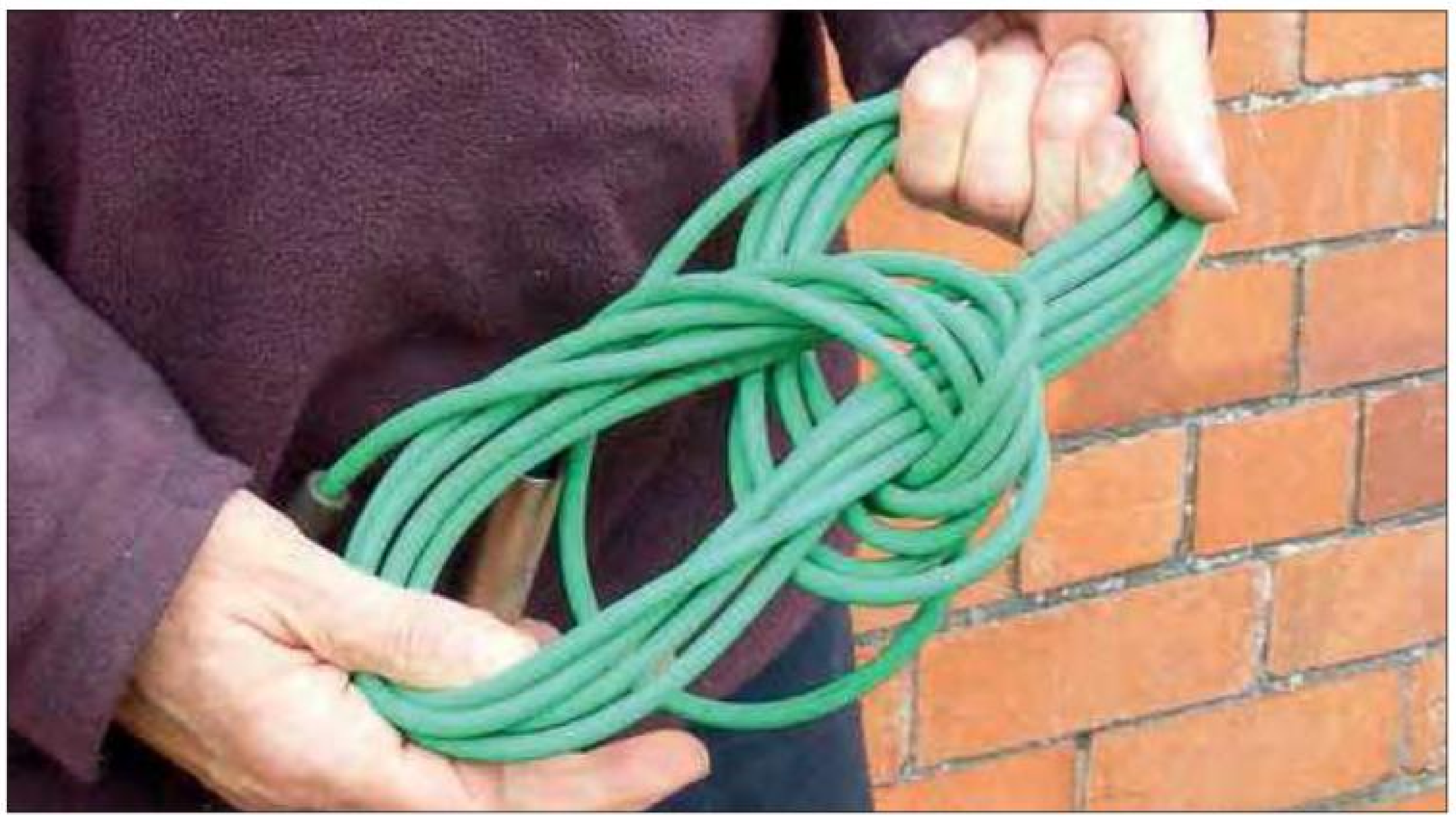


Fig.37. Knotting cable for storage just damages it even more.

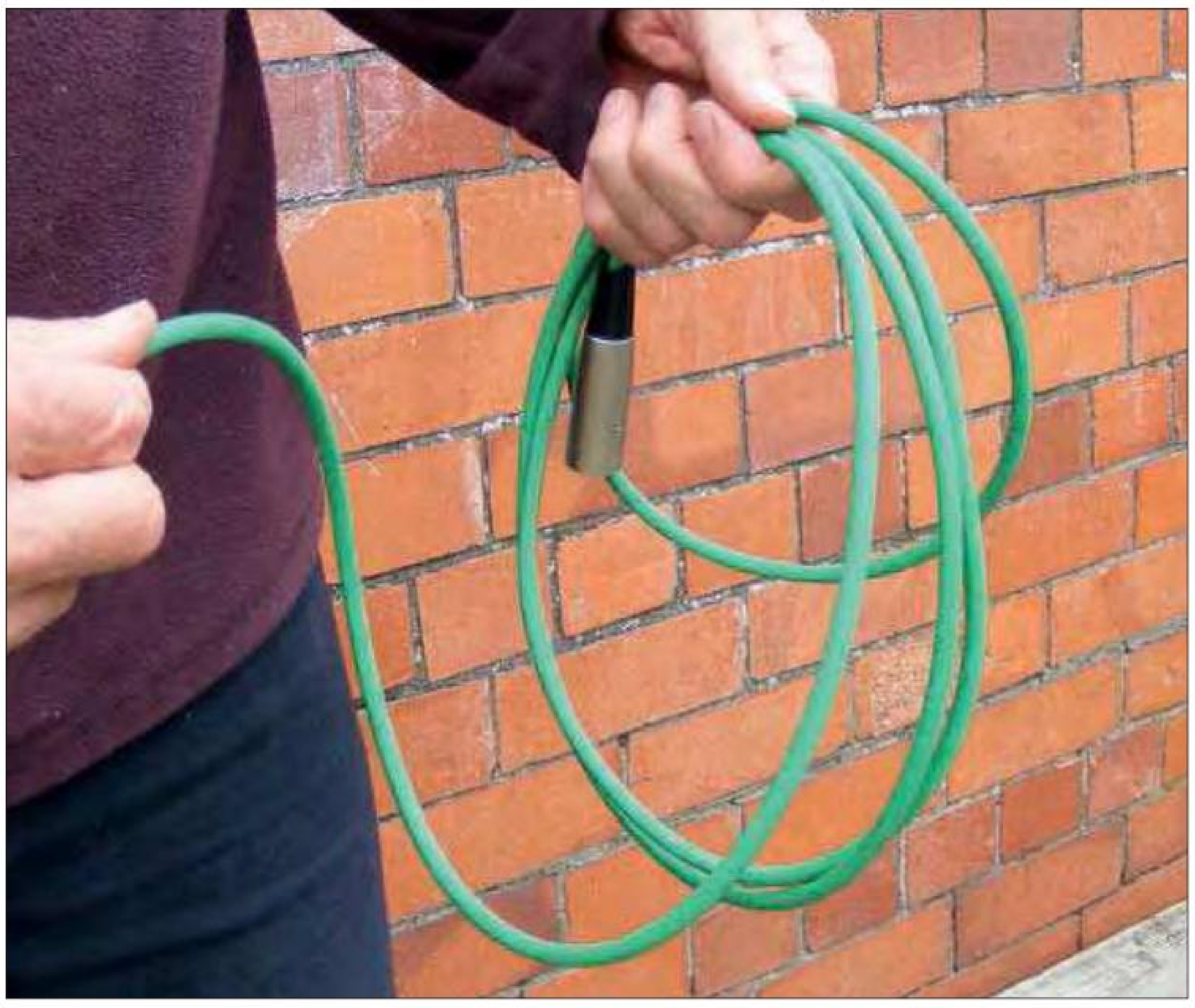


Fig.38. Roadies wind a cable up like this, with a twist of the wrist while feeding it into the coil to prevent kinks.

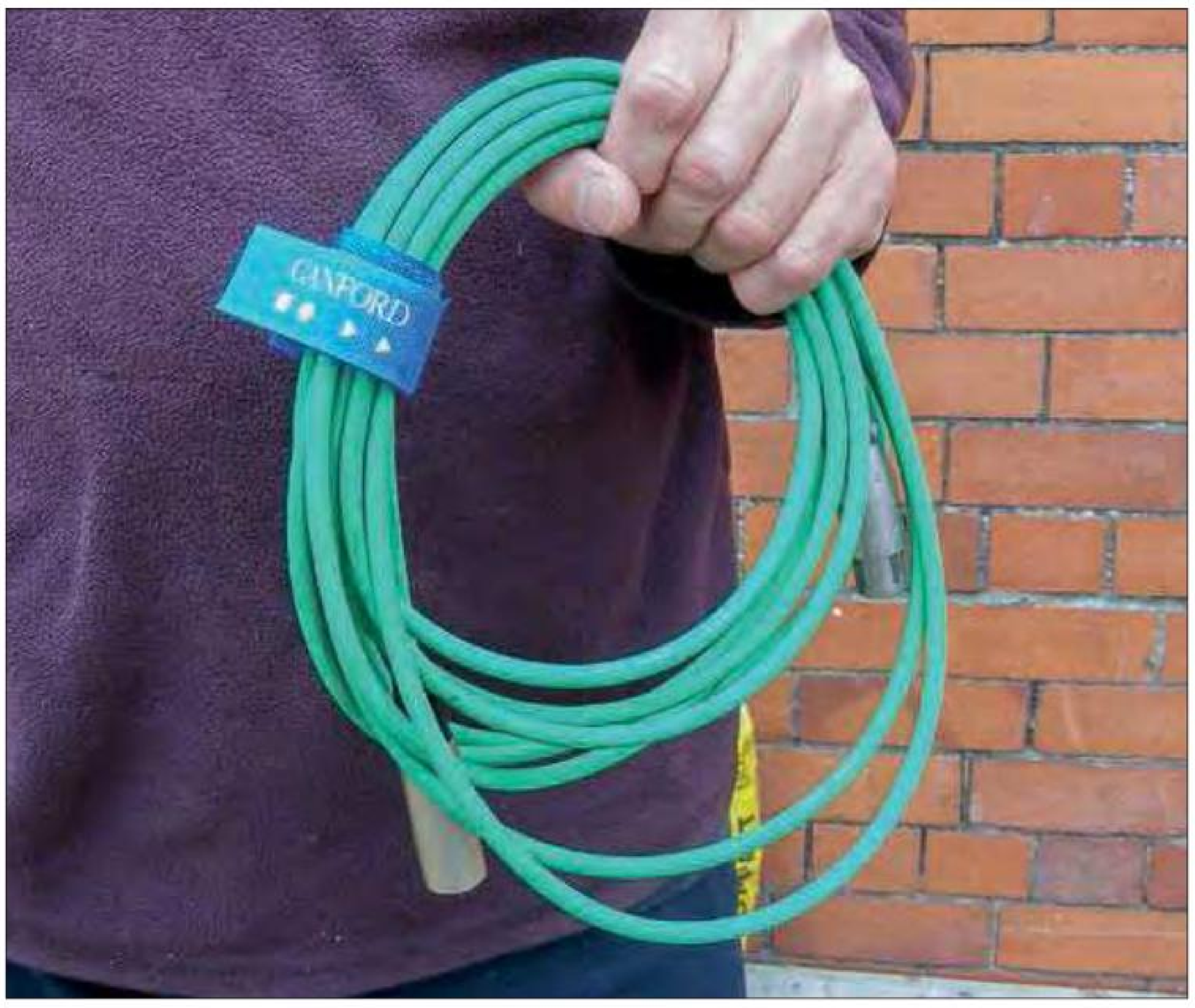


Fig.39. Velcro ties are a good way to prevent the cable unwinding. A cheaper option is releasable nylon cable ties.

present on the female connectors only. Latching is a mixed blessing; on the one hand connectors don't fall out, on the other, equipment can be pulled off stands and benches if a lead is tripped over. These latches are removable – but don't do it on the microphone end if you have a singer who swings the mic by its lead!

Testing

Always test your cables for continuity and shorts. A simple cable tester by Brooke Siren Systems is shown in Fig.33. Two LEDs illuminating at the same time indicates a short. If the wrong led illuminates for the respective switch it suggests a couple of wires are crossed, such as a phase flip. It's worth making one of these (see Fig.34). They are also handy for holding XLR inserts when soldering; alternatively, I sometimes use old speaker magnets for holding cables while soldering, as shown in Fig.35.

Cables usually break at the connector ends – the points of worst mechanical stress. If you have a capacitance meter you can detect which end the cable is broken, a technique familiar to most telecoms wiremen. You measure the capacitance across pins 2 and 3. The fault is located at the end with the least capacitance. If there is equal capacitance at both ends then the break would be in the middle, but I've never known this happen.

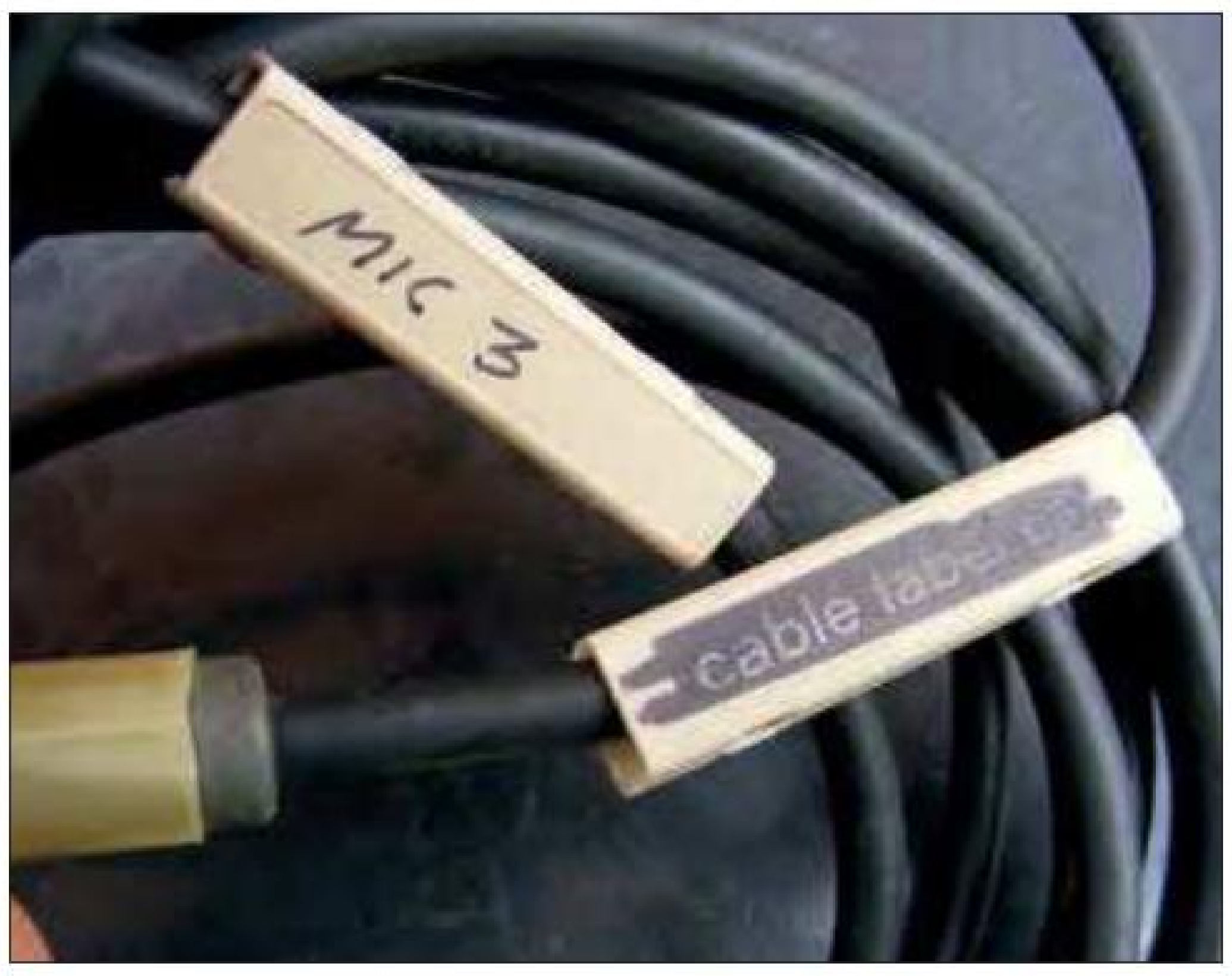


Fig.40. All large installations need careful labelling. These clip-on labels are useful.

Fig.41. This pile of home-made mic cables has been earning its keep since 1984.

Winding up

Many audio cables are prematurely aged by improper coiling. The *wrong* way is to tightly coil it against your elbow, as shown in Fig.36. Worse, some people then go and knot it together to stop it uncoiling (Fig.37). The correct 'roadie' way of doing things is to hang the coil loosely in one hand and gently feed it in with an untwisting action, as shown in Fig.38. Finally, a Velcro tie should be used to hold it together (Fig.39). In complex set-ups it's necessary to label cables. There are many systems. Fig.40 shows a clip-on type. Don't use PVC insulation tape, since the glue draws the plasticiser out of PVC jackets and makes a sticky mess. Fig.41 shows a box of mic cables typical of a small band.

Last, here are a couple of useful links on all the permutations of balancing. These two Rane company notes provide lots of different lead permutations and a good summary of AES48 (only accessible free if you are a member of the AES): **www.ranecommercial.com/legacy/note110.html** and **www.ranecommercial.com/legacy/note151.html**

Max's Cool Beans

By Max the Magnificent

Flashing LEDs and drooling engineers – Part 20

As I pen these words, I've just returned from Silicon Valley where I was working on a rush job of a nature I am unable to disclose for a company whose name must remain unspoken with individuals whose identities I am not at liberty to reveal. But I fear I've already said too much.

On the one hand, this was a lot of hard work, rising at 5:30 in the morning and working until 11:00 at night before staggering back across the road to the conveniently located hotel to start anew the next day. On the other hand, it was a lot of fun because I was working with the *crème de la crème* of techno-dweebs. Of course, this meant I had to be in a position to establish my own techno-cred, as it were. Fortunately, to bolster my modest skills, I had recently taken possession of a new smart business card, which offered a useful distraction (Fig.1).

This laser-etched wooden beauty – they also have plastic versions – was kindly gifted to me by the folks at Mobilo. I opted for the wood version because I am enamored by the 'steampunk' aesthetic.

Now, you may be thinking, 'Ho hum, a wooden business card, what's so great about that?' Well, if you had your smart phone handy, I'd show you. The point is that you don't need to waddle around staggering under the weight of a bunch of these cards – one is plenty. All I need to do is wave my card over a smartphone equipped with NFC (near-field communication) capability, and my contact details – including my photo, name, company name, address, telephone number and website – pop up on the screen. With just a single tap of the finger, the phone's owner can add me to their contacts list.

Quite apart from anything else, when one is living in the middle of a worldwide pandemic, this 21st century business card technology prevents any embarrassment or worry associated with accepting a potentially disease-ridden traditional business card. An added advantage for me is that this card acts like fish bait when I'm swimming with a techno-weenie crowd (you can discover more at: **MobiloCard.com**).

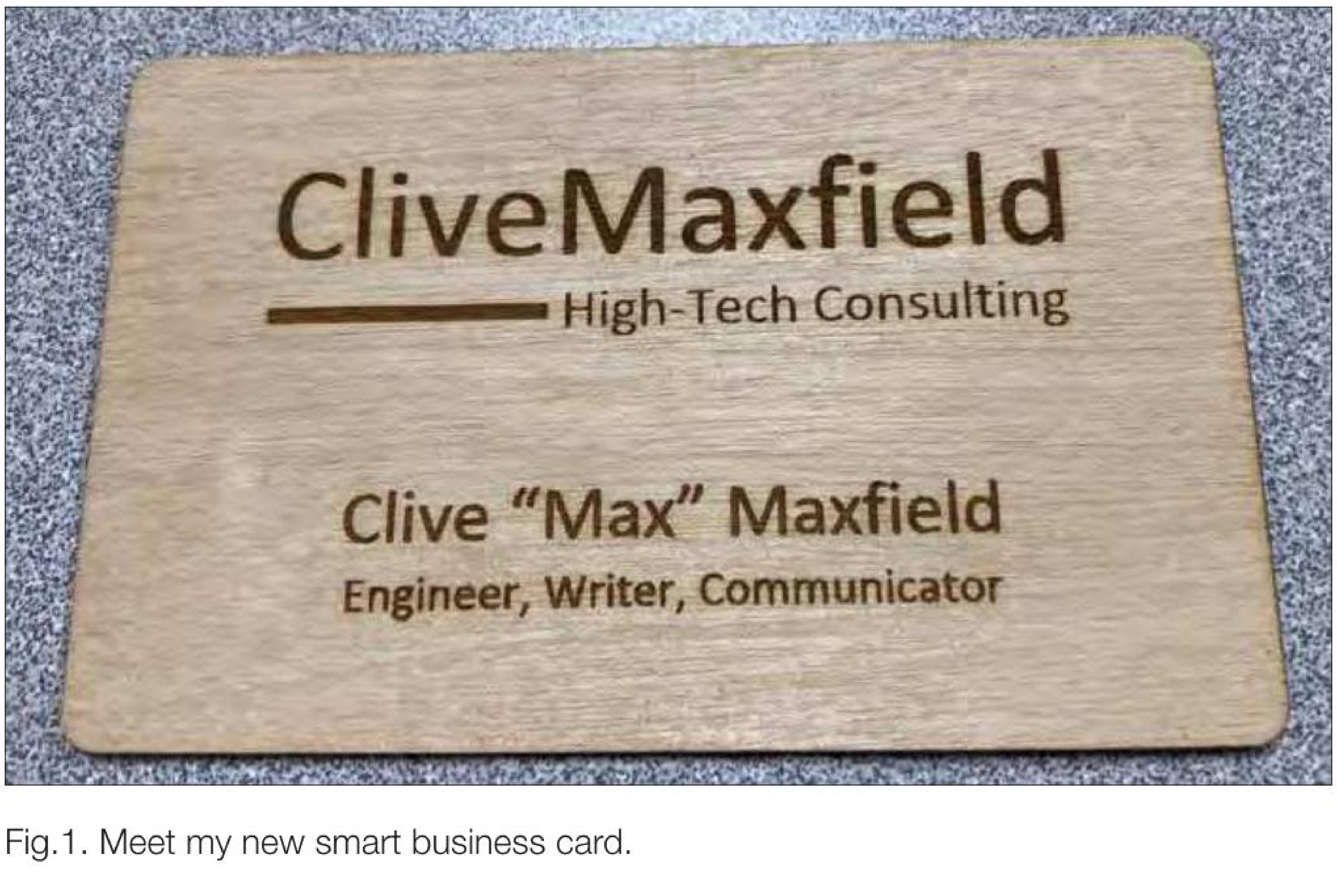


Fig.1. Meet my new smart business card.

GROK is a four-letter word

The word 'grok' is a neologism coined by American writer Robert A. Heinlein for his 1961 science fiction novel *Stranger in a Strange Land*. The *Oxford English Dictionary* summarises the meaning of grok as: 'to understand intuitively or by empathy, to establish rapport with' and 'to empathise or communicate sympathetically (with)'; also, 'to experience enjoyment.' (Heinlein's concept was a little more nuanced than any of these, but I'm sure you get the drift.)

The reason I mention this here is that, in my previous column (*PE*, September 2021) I mentioned that one of the things I am planning on doing with my 10-character *Victorian Display* (where each character is formed from 21-segments) is to implement a version of the word art piece that was created by Matt Gorbett in 2007 (**https://bit.ly/2THZLQf**). As part of this, I'm going to mount a potentiometer below each of my characters.

In Matt's implementation, he started by displaying the message 'I #### YOU' (which will consume all 10 characters of my display when we count the two spaces). The idea is that a causal passerby can use the potentiometers under the four blank characters to add a word that expresses a sentiment like 'I LOVE YOU' (hopefully they refrain from declaring 'I HATE YOU,' otherwise someone will end up sleeping on the sofa). After a few seconds to allows the user to contemplate their statement, the system starts to swap individual letters to form alternative messages until eventually returning to its original 'I #### YOU' state.

So, how many four-letter words are there? Well, if we were to include every combination, we'd have 26 * 26 * 26 * 26 = 456,976. In reality, of course, we don't use many of these permutations for one reason or another, including those that graunch on our ears. It's been a long time since I felt the urge to *xqzn* my *oiwk*, for example (I'm not as flexible as I used to be). I just had a quick Google while no one was looking to discover that, according to the *Official Scrabble Player's Dictionary, Volume 6*, there are 3,996 legal four-letter words.

As an aside, **Word-Buff.com** informs us that, while 93 of these four-letter words claim three vowels and one consonant, only one four-letter word is composed exclusively of vowels: EUOI, which was, 'a cry of impassioned rapture in ancient Bacchic revels,' although I think I expressed much the same sentiment when I once dropped a hammer on my foot. By comparison, 47 four-letter words are formed using only consonants, eg, HYMN: a religious song or poem of praise to a god, LYCH: the Saxon word for a dead body (possibly someone whose hymns were deemed to be unsatisfactory), and MYTH: a widely held but false belief or idea (such as the notion that I have a clue what I'm talking about).

But we digress... Let's assume we have our list of 3,996 four-letter words stored in our microcontroller's memory. This will require 15,984 bytes of memory (one byte for each letter), which would be a problem for an Arduino Uno, but it's not an issue when we remind ourselves that I'm using a Teensy 3.6 to drive my *Victorian Display*, and this little beauty boasts 1MB of Flash and 256KB of RAM.

So, how are we going to generate derivative words based on the original selection entered by our passerby? The simplest technique would be to simply search for any random word that differs from our current word by a single letter and swap that letter out, then keep on repeating the process for some number of cycles before returning to the 'I #### YOU' state. On the one hand, we will end up with a lot of nonsensical sentences; on the other hand, we might be surprised and delighted by an unexpected expression.

Another possibility would be to associate each of the words in our list with its logical opposite, such as LOVE and HATE, and then have the system create a word ladder, which is based on a word game invented by Lewis Carroll. A word ladder puzzle begins with two words. To solve the puzzle, one must find a chain of other words to link the two, in which each pair of adjacent words differ by only one letter. For example, LOVE, LAVE, LATE, HATE (or LOVE, LOOE, LOOK, GOOK, GROK).

But before I start rooting around for an algorithm to implement this, I thought I'd throw things open to discussion. Can you think of any other form(s) of word play we might decide to employ for this task? If so, please feel free to drop me an email and share your ideas.

It's a SMAD, SMAD, SMAD, SMAD world!

I have no idea why, but I was just thinking about the 1963 American comedy film *It's a Mad, Mad, Mad, Mad World* with its all-star cast, including Spencer Tracy, Buddy Hackett, Mickey Rooney, Ethel Merman, and Phil Silvers. As a kid, I also used to love watching Phil Silvers and the gang in the *Sergeant Bilko* sitcom (officially known as *The Phil Silvers Show*), which originally ran from 1955 to 1959.

'Not a lot of people know that' is a catchphrase that is commonly associated with Sir Michael Caine. Well, not a lot of people know that the American animated sitcom *Top Cat*, which originally aired from 1961 to 1962, had its roots in *Sergeant Bilko*. For example, the *Top Cat* character was voiced by Arnold Stang, whose vocal characterisation was based on an impression of Phil Silvers. Furthermore, Maurice Gosfield, who played Private Duane Doberman in *Sergeant Bilko*, also provided the voice for Benny the Ball in *Top Cat*.

I'm sorry. What were we talking about? Oh yes, *Steve and Max's Awesome Displays* (*SMADs*), each of which boasts 45 tricolour LEDs. As we previously discussed (*PE*, August 2021), these displays – which were conceived and created by Steve Manley and yours truly – can be enhanced by the addition of 'shells' that compartmentalise the light from the LEDs. We currently have two different types of shells allowing us to create 29-segment displays (in which 13 of the shells' compartments have one LED and 16 compartments have two LEDs), and 45-segment displays (in which each compartment has its own LED).

In my previous column (*PE*, September 2021), I made mention of the fact that I've created two 'robot heads,' each of which boasts two *SMADs*. One head features two 29-segment displays, while the other flaunts two 45-segment displays. These are fixed structures at the moment, but a project for the future may be to create upgraded versions with sensors (to detect the presence of people and to locate the source of sounds) and servos (to pan and tilt the heads), thereby allowing their *SMAD* eyes to follow you around the room (be afraid, be very afraid). Also in that issue, we introduced the LED and segment map for the 29-segment versions of these displays (Fig.2). The numbers, which are applicable to both types of *SMAD*, refer to the positions of the LEDs in the string, while the letter combinations are the names we use to identify the segments in the 29-segment versions.

Just call me Don Quixote

You may recall that Steve created a cunningly cool video that compares and contrasts a bare *SMAD*, a *SMAD* with a 29-segment shell, and a *SMAD* with a 45-segment shell (**https://bit.ly/2VNhhUh**). Steve demonstrates all sorts of cunningly colourful effects in this video, and we will build up to these sophisticated presentations over time. However, before we run, we first have to learn to walk, so we are going to take things step-by-step, starting with a simple pinwheel or windmill effect (Don Quixote – tilting at windmills – I'm sorry, sometimes I just can't help myself).

We will start with a simple effect where just one windmill arm sweeps around in a circle (Fig.3a). Don't forget that, should you wish to join in the fun, frivolity, giddiness and gaiety, then *SMADs* are available for purchase from the *PE PCB Service* (**https://bit.ly/3wVUgLq**) for the remarkably low price of only £11.95 each, which includes shipping in the UK (shipping outside the UK will be quoted separately).

As usual, we won't present complete programs here, but you can follow along by downloading the code from the October 2021 page of the *PE* website at: **https://bit.ly/3oouhbl**). You'll find our first sketch (program) in file **CB-Oct21-01.txt**

Let's start by discussing some housekeeping tasks. In an earlier column (*PE*, October 2020), we created some useful utility functions called `GetRed()`, `GetGreen()` and `GetBlue()`, each of which accepts a 24-bit colour value as input (actually, it's a 32-bit word, but only 24 of the bits are used) and returns its corresponding 8-bit colour channel value. We also created a `BuildColor()` function that accepts three 8-bit red, green, and blue colour components and returns the corresponding 24-bit colour value. The point is that you will find these utility functions in our sketch, along with a `ModifyBrightness()` function that accepts a 24-bit colour as input and returns a diminished version that's been dimmed-down to a specified percentage of the original.

Consider the `ModifyBrightness()` function – which I'm mainly using when I want to dim things down to take videos – it's worth noting that we perform the multiplication followed by the division and not the other way round. For example, assuming we wish to modify the red channel to be only 20% of its original brightness, then the algorithm we use is (red * 20) / 100. If we were performing this calculation using pencil and paper based on real numbers with fractional components, then we could achieve the same result using (red / 100) * 20. The reason we can't use this latter approach in our program is because an integer division truncates any remainder, which means we might discard useful information before performing the multiplication, thereby diminishing the fidelity of our result.

I've decided that I want the arm of my windmill to perform a full rotation of the display each second, so I've defined a `CYCLE_TIME` of 1000 milliseconds. I've also defined `NUM_NEOS_PER_SMAD` (the number of LEDs forming each *SMAD*) to be 45.

In my case, I have four *SMADs* (two for each of my 'robot heads'), so I've defined `NUM_SMADS` to be 4. You can change this value to reflect the number of *SMADs* at your disposal. I've also daisy-chained all of my *SMADs* together to form a single string of 45 × 4 = 180 LEDs, so I've defined `NUM_NEOS` to be (`NUM_NEOS_PER_SMAD * NUM_SMADS)`. The idea is that, if you have only two *SMADs*, for example, then all you have to do is to change the value associated with `NUM_SMADs` for these programs to work with your displays.

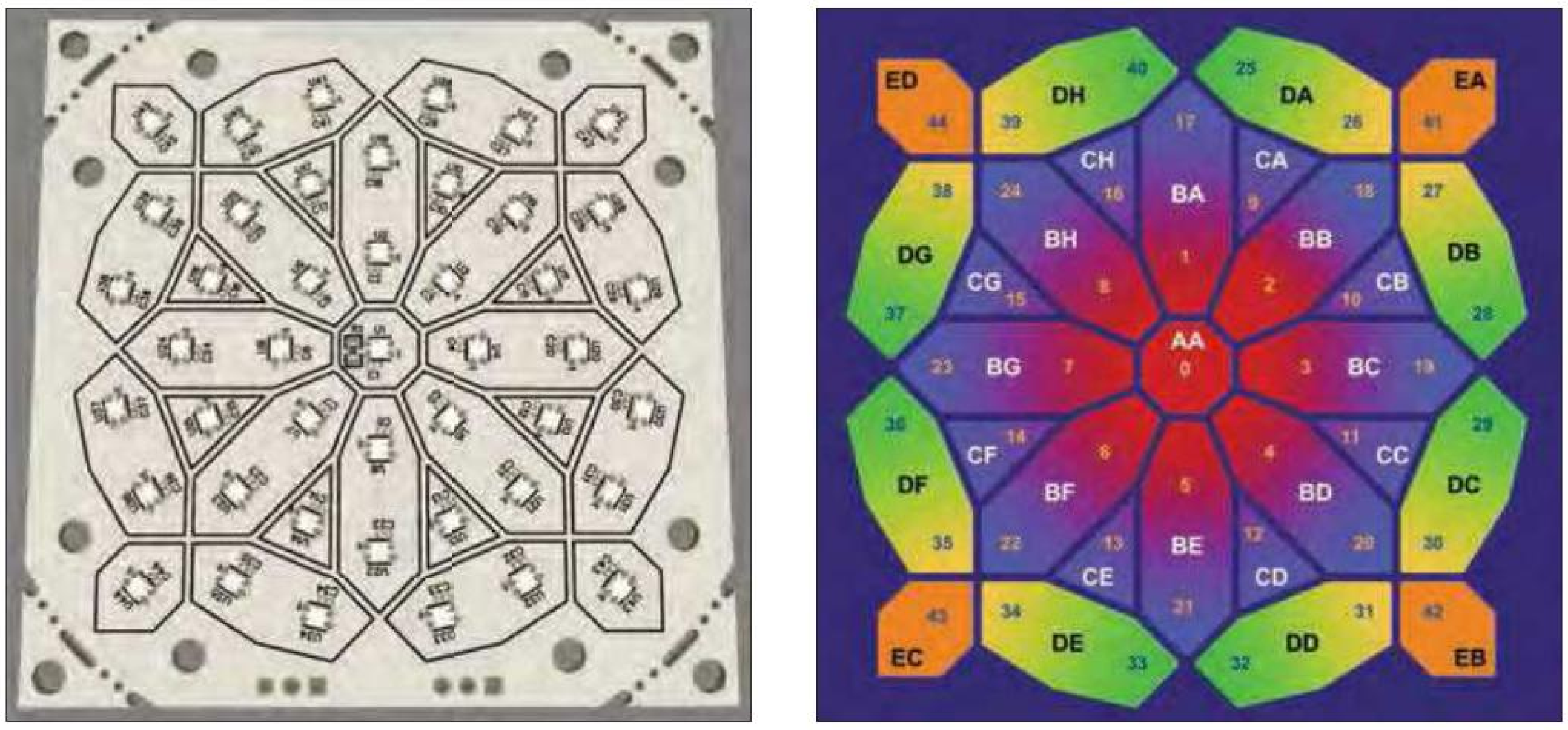


Fig.2. *SMAD* board (left), LED and segment map (right) (Image source: Steve Manley).

Hold onto your hat!

I hope you are sitting comfortably because things are about to get exciting. For this first effect, I've defined `NUM_PATTERNS_IN_EFFECT` as being 8 (this corresponds to the fact that we have 8 'spokes', as illustrated in Fig.3a), and `MAX_LEDS_IN_EFFECT` as being 2 (there are two LEDs in each spoke). Using these, I've created a two-dimensional array of 8-bit integers called `EffectMap[][]`, that is comprised of `NUM_PATTERNS_IN_EFFECT` (ie, 8) rows, each containing `MAX_LEDS_IN_EFFECT + 1` (ie, 3) items. We initialise this array as follows:

```
{
  {2, 1, 17}, // BA
  {2, 2, 18}, // BB
  {2, 3, 19}, // BC
  {2, 4, 20}, // BD
  {2, 5, 21}, // BE
  {2, 6, 22}, // BF
  {2, 7, 23}, // BG
  {2, 8, 24}  // BH
};
```

The first element in each row tells us how many LEDs we are using to form this pattern, while the remaining values are the numbers of the LEDs in question. For example, the first row tells us that we are dealing with 2 LEDs numbered 1 and 17. From Fig.2, we know that these LEDs correspond to segment BA, which is the vertical spoke in our windmill.

Of course, you might feel that – since there are two LEDs in every pattern – defining this in the first element of each row is a waste of time, space and effort, but we are establishing a foundation for what is to come.

Last but not least, we've defined a background colour and a foreground colour. At some stage in the future, we will experiment with making one or both of these colours dynamic (eg, a rippling rainbow). For the moment, however, we will stick with static values. In the case of this column's code, we are using a background colour of red with a default value of 25% brightness, and a foreground colour of white with a default value of 100% brightness. The actual values displayed for both of these colours are further modified by our `ModifyBrightness()` function.

Now, let's jump to the main `loop()` function. If you have only recently joined our party, you may be surprised to see that we don't make use of the Arduino's `delay()` function. Instead, every time we roll around the loop, we check to see if a certain interval has elapsed, as defined by a variable called `IntervalTime`, which has been set to `CYCLE_TIME` (one second) divided by the number of patterns in our effect. If this interval has elapsed, we first set the LEDs in the current pattern to be the background colour and we then set the LEDs in the new pattern to be the foreground colour. This technique was introduced in the *Dump the delay* topic in an earlier column (*PE*, December 2020).

Let's look at this in a little more detail. In the case of this particular program, we have a variable called `EffectMapIndex` that we use to point to the current row (pattern) of interest in our two-dimensional `EffectMap[][]` array. We start by determining how many LEDs we have in the current pattern:

```
numLeds = EffectMap[EffectMapIndex][0];
```

Using this information, we set the LEDs in the current pattern to the background colour:

```
for (int iLed = 1; iLed <= numLeds; iLed++)
{
  int iNeo = EffectMap[EffectMapIndex][iLed];
  Neos.setPixelColor(iNeo, BackgroundColor);
}
```

Next, we increment our index to point to the next pattern (the use of the '%' modulo operator was discussed in detail in an earlier *Cool Beans* column: *PE*, March 2021):

```
EffectMapIndex = (EffectMapIndex + 1)
                 % NUM_PATTERNS_IN_EFFECT;
```

Once again, we determine how many LEDs we have in this new pattern, then – using this information – we set the LEDs in this new pattern to the foreground colour.

The more the merrier

As we see, implementing a simple windmill effect using one arm (segment) on one *SMAD* is 'easy peasy lemon squeezy' as they say in the US (we certainly wouldn't want it to be the opposite, which would be 'stressed depressed lemon zest').

Suppose we wish to control additional *SMADs* that are daisy-chained together – for example, the four *SMADs* in my two robot heads.

Let's consider the part where we set the LEDs in the current pattern to the background colour. As a 'cheap-and-cheerful' (also known as 'quick-and-dirty') technique, we could simply use the following (you can see the full listing of the program in the download file: **CB-Oct21-02.txt**):

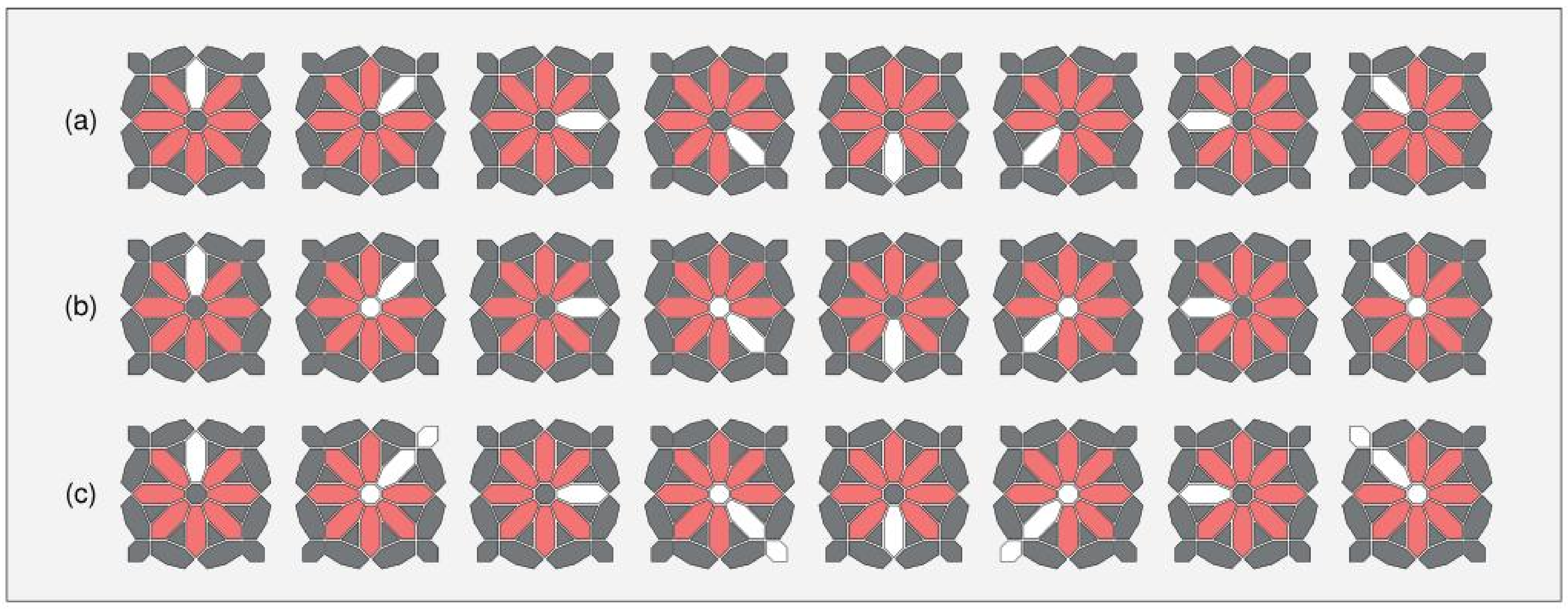


Fig.3. Variations on a simple windmill effect.

```
for (int iLed = 1; iLed <= numLeds; iLed++)
{
  int iNeo = EffectMap[EffectMapIndex][iLed];

  Neos.setPixelColor((iNeo +   0), BackgroundColor);
  Neos.setPixelColor((iNeo +  45), BackgroundColor);
  Neos.setPixelColor((iNeo +  90), BackgroundColor);
  Neos.setPixelColor((iNeo + 135), BackgroundColor);
}
```

Instead of writing to one LED, we now write to four of the little rascals using a 45-pixel offset each time (the only reason we add 0 in the first statement is for completeness – the compiler will remove this from the subsequent machine code). We would apply a similar treatment when we come to setting the LEDs in the new pattern to the foreground colour.

The problem with this approach is that it's hard-coded. That is, if you have only two *SMADs*, for example, you would have to comment-out (or delete) some of the lines. A more generic approach is as follows (here we are setting the current pattern to the background colour):

```
numLeds = EffectMap[EffectMapIndex][0];

for (int iSmad = 0; iSmad < NUM_SMADS; iSmad++)
{
  int smadOffset = iSmad * NUM_NEOS_PER_SMAD;

  for (int iLed = 1; iLed <= numLeds; iLed++)
  {
    int iNeo = EffectMap[EffectMapIndex][iLed];
    Neos.setPixelColor((iNeo + smadOffset),
                                BackgroundColor);
  }
}
```

As we see, we create an outer loop that cycles through all of the *SMADs*, and then we calculate the number of the pixel to be modified based on the current *SMAD*. We would perform a similar treatment with regard to setting the new pattern to the foreground colour (you can see the full program in file **CB-Oct21-03.txt**).

Variations on a theme

Even though our current windmill effect with its single arm is rudimentary, it still gives us the ability to perform some interesting experiments. For example, suppose we wish to pulse the center segment such that it is on whenever the arm is pointing NE, SE, SW and NW, and off whenever the arm is pointing N, E, S and W (Fig.3b). Take a moment to think how we might set about doing this.

In fact, all we need to do is modify our `MAX_LEDS_IN_EFFECT` definition to be 3, and then update the contents of our `EffectMap[][]` array to be as follows; the rest of the program stays as-is (you can see the full program in file **CB-Oct21-04.txt**):

```
{
  {2, 1, 17,  0}, //    BA
  {3, 0,  2, 18}, // AA BB
  {2, 3, 19,  0}, //    BC
  {3, 0,  4, 20}, // AA BD
  {2, 5, 21,  0}, //    BE
  {3, 0,  6, 22}, // AA BF
  {2, 7, 23,  0}, //    BG
  {3, 0,  8, 24}  // AA BH
};
```

One thing you might find confusing is the '0' values in this array, which we are using for two different purposes. In the case of the rows that have 3 LEDs in their patterns, the 0s in the second column refer to the LED associated with segment AA. By comparison, in the case of the rows that have only two LEDs in their patterns, the 0s in the fourth column serve only as space fillers – we could assign any value to these, and it wouldn't have any effect because we never use them. (As an aside, we used unsigned 8-bit integers to form this array. If we had opted to use signed 8-bit integers, I would probably have assigned –1 values to these space filler items, thereby providing a visual clue that they were 'special.')

As one final variation on this theme, suppose we now decided to augment our current version of the program with the ability to illuminate the EA, EB, EC and ED segments when the arm is in its NE, SE, SW and NW positions, respectively (Fig.3c). Once again, all we need to do is modify our `MAX_LEDS_IN_EFFECT` definition to be 4, and then update the contents of our `EffectMap[][]` array to be as follows (you can see the full program in file **CB-Oct21-05.txt**):

```
{
  {2, 1, 17,  0,  0}, //    BA
  {4, 0,  2, 18, 41}, // AA BB EA
  {2, 3, 19,  0,  0}, //    BC
  {4, 0,  4, 20, 42}, // AA BD EB
  {2, 5, 21,  0,  0}, //    BE
  {4, 0,  6, 22, 43}, // AA BF EC
  {2, 7, 23,  0,  0}, //    BG
  {4, 0,  8, 24, 44}  // AA BH ED
};
```

For your delectation and delight, I've just created a short video showing all of these test cases in action in gloroius technicolor: **https://youtu.be/BBFFyQP_yhE**

It's your turn!

I don't think it's fair for me to be having all the fun (and doing all the work). How about you jump into the fray with gusto and abandon? For example, how would you go about modifying our latest program so that it has four patterns each with two arms at 180° to each other?

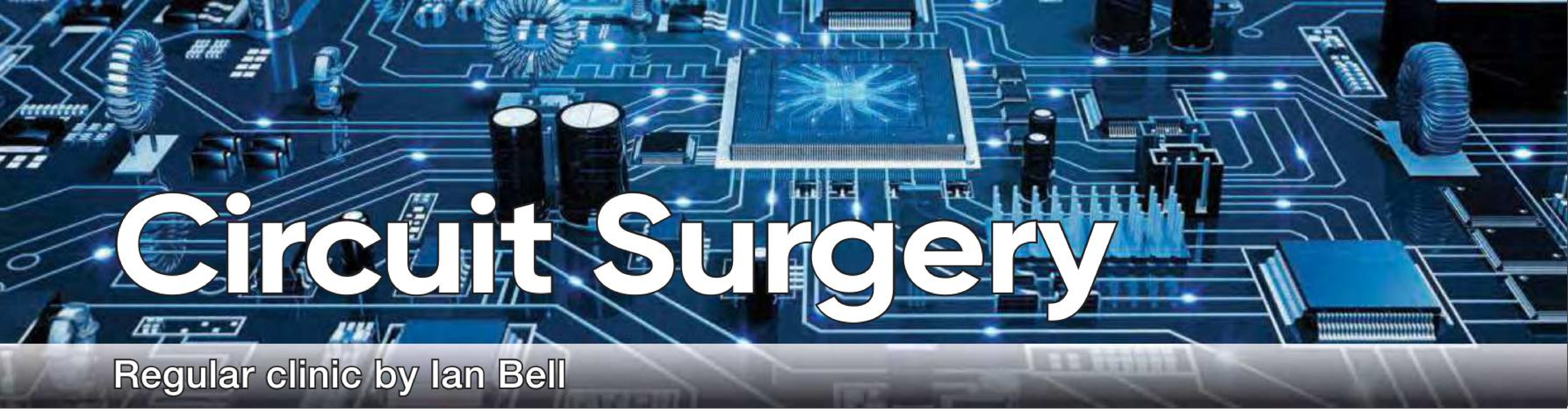
Next, how would you modify this latest incarnation such that the windmill patterns on one of the *SMAD's* eyes rotate clockwise while the other *SMAD's* eyes rotate anticlockwise?

As another thought experiment, you might want to consider how to implement a program involving two or more *SMADs* that starts with them each displaying a single windmill arm pointing upwards. We start with the least-significant *SMAD* (the one on the right) spinning its arm clockwise completing a full rotation each second. Every time this arm returns to its vertical position, the arm on the adjacent *SMAD* advances by one position (pattern). Similarly, every time the arm on the second *SMAD* returns to its vertical position, the arm on the third *SMAD* advances by one position, and so on for all of the *SMADs* in the chain.

Finally, remembering that I eventually intend for the *SMADs* in my robot heads to give the impression that they are acting as eyes, this would be a good time for us to start cogitating and contemplating on which colour and segment combinations we could use to make them appear to be looking left, right, up, down and straight ahead. Also, can we use different combinations of colours and segments to reflect emotions, like happy, sad or angry, for example? As always, I welcome your comments,

Cool bean Max Maxfield (Hawaiian shirt, on the right) is emperor of all he surveys at **CliveMaxfield.com** – the go-to site for the latest and greatest in technological geekdom.

Comments or questions? Email Max at: **max@CliveMaxfield.com**



Circuit Surgery

Regular clinic by Ian Bell

Electrical Overstress Protection for Circuits

Recently, Jose Cordero posted a question on the EEWeb concerning protection for sensor circuit inputs. He wrote: 'I am building with a sensor that will be capable of measuring voltages between 25-40V through the ADC of a microcontroller, and at the same time feeding on these voltages. A fundamental part of every sensor is to have an overvoltage protection circuit, to take care of the microcontroller and any extra components from any overvoltage that happens in the future'. He went on to mention crowbar circuits as potential protection and asked for help on a circuit design. We will not look at this specific circuit but will consider in more general terms the problem of protecting inputs of components such as op amps, analogue-to-digital converters (ADCs) and microcontrollers. This is a common requirement for sensing and measurement circuits, particularly where the inputs may be connected to a variety of sources during use, or where the environment may cause problems; for example, due to issues with power supply lines or the effects of induction or electromagnetic interference. Before looking at input overvoltage protection we will look briefly at circuit protection more generally and a range of devices which are used in protection circuits.

We mentioned overvoltage, but in general the term 'electrical overstress' (EOS) is used to cover situations where a circuit or device is subjected to levels of voltage, current or power which cause damage. There are many ways in which EOS can occur, from simply connecting a circuit incorrectly to complex powerline noise issues in industrial installations. Devices do not even have to be in a circuit to suffer EOS – it is well known that many semiconductors (particularly integrated circuits) can be damaged by electrostatic discharge (ESD) during handling. For example, the charge built up on a person can be discharged through a device when it is touched, delivering sufficient energy to destroy it.

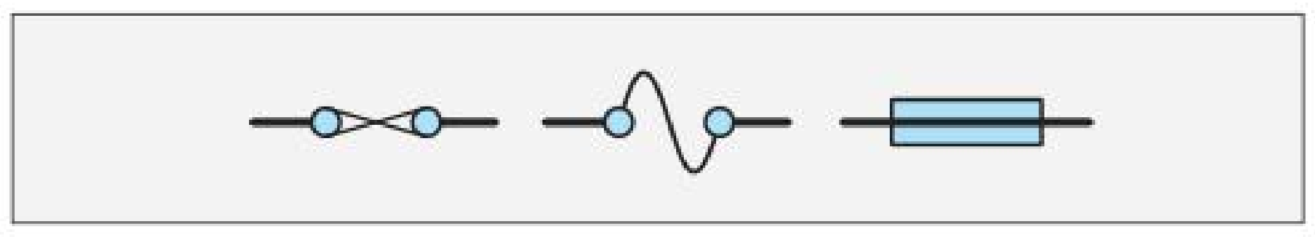


Fig.1. Fuse circuit symbols.

Simulation files

Most, but not every month, LTSpice is used to support descriptions and analysis in *Circuit Surgery*.
The examples and files are available for download from the *PE* website.

Overcurrent protection devices

There are a number of components which are specifically used for protection against EOS. The most well-known of these is the fuse (see Fig.1 for circuit symbol). This is an overcurrent protection device comprising a wire or strip of conductor, designed so that heat generated by the current flowing in it will cause it to melt above a certain rated current. This causes an open circuit to occur, which stops the excessive current. Once a fuse has blown it must be replaced – but, crucially, the cause of the problem must be identified and fixed first.

Fuses are typically used in protection and safety roles where EOS will cause damage or danger that cannot easily or cheaply be prevented by more sophisticated circuits that temporarily apply protection when needed. Fuses may be used along with other protection as a last resort, and for safety when other protection might be overwhelmed. Fuses respond to overcurrent but when used together with overvoltage protection may blow if activation of the overvoltage protection results in increased current flow (which it often does). For this to occur the fuse must be 'upstream' of the overvoltage protection (closer to the input or power source than circuit under protection).

The most obvious parameter when selecting a fuse is the current at which it will blow, but it is also necessary to consider the response time. Fuses may respond too slowly to protect circuitry in some situations (although specifically fast-reacting fuses are available) – on the other hand, some systems draw high currents for short periods under normal conditions (eg, motors at start-up) and may require time-delay (or 'slow-blow') fuses which can tolerate higher currents for short periods. Fuses also have maximum voltage and fault current levels at which they can be safely used. For situations where the overcurrent may be much larger than the operating current and there is a risk of damage from excessive energy then high-rupture capacity (HRC) fuses can be used. These have a more advanced structure than simple straight-wire-in-glass-tube basic fuses. HRCs are tightly sealed and contain fillings (such as silica sand) which help absorb energy and prevent arcing.

Care with protection device use

As we will mention again later, inserting any component in a circuit to help protect it will change its electrical characteristics – adding some combination of parasitic resistance, capacitance and inductance, and possibly leakage current. For fuses, the resistance and inductance are likely to be most important. In some cases, these parasitics are too small to have any impact, but in situations such as the inputs of high-performance signal processing, protection components may have a significant effect.

Polymeric devices

An alternative to fuses in situations where it is inconvenient, or very difficult to

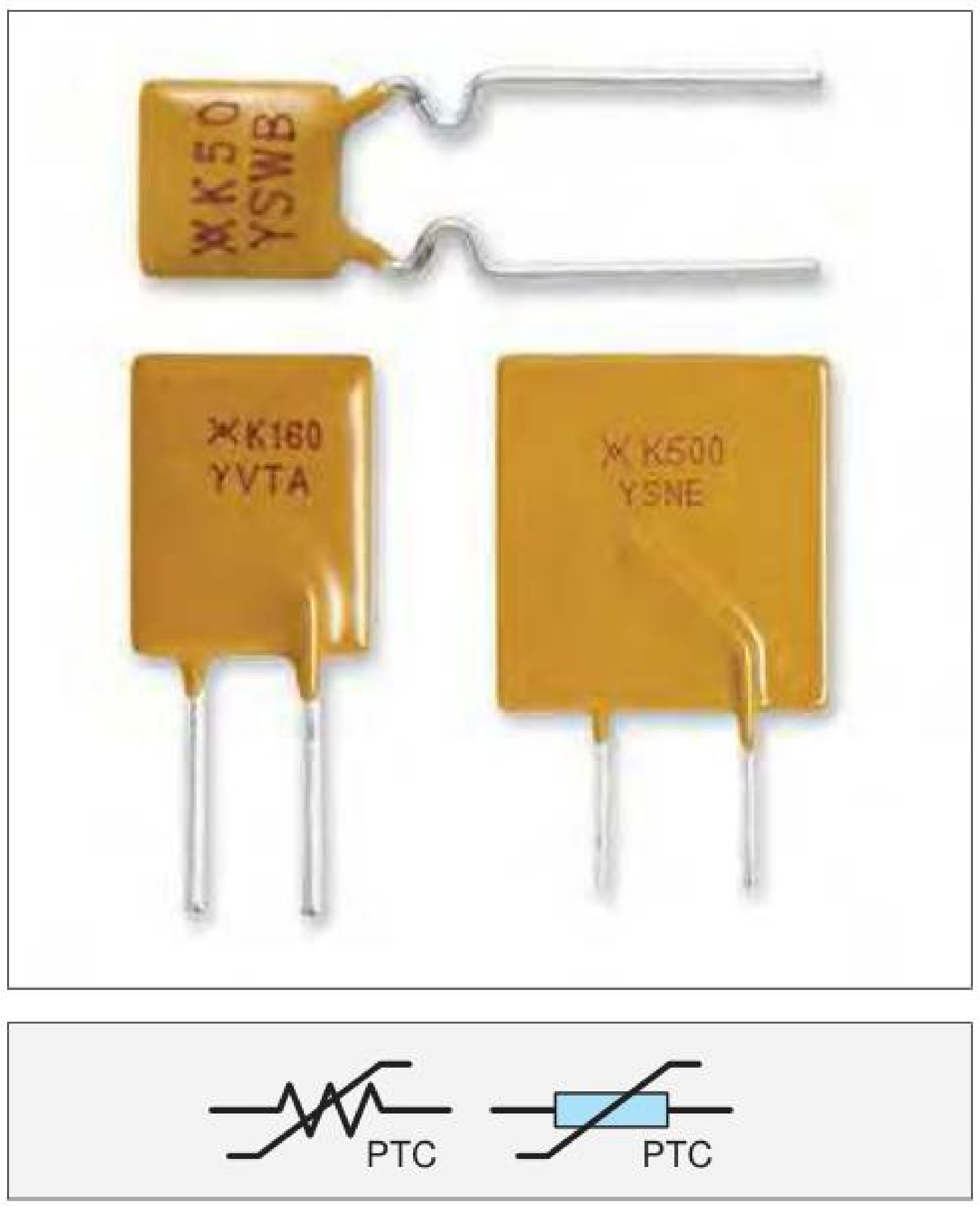


Fig.2. (Top) A selection of radial-leaded resettable PPTC polyswitches from Littelfuse; (below) PTC circuit symbols.

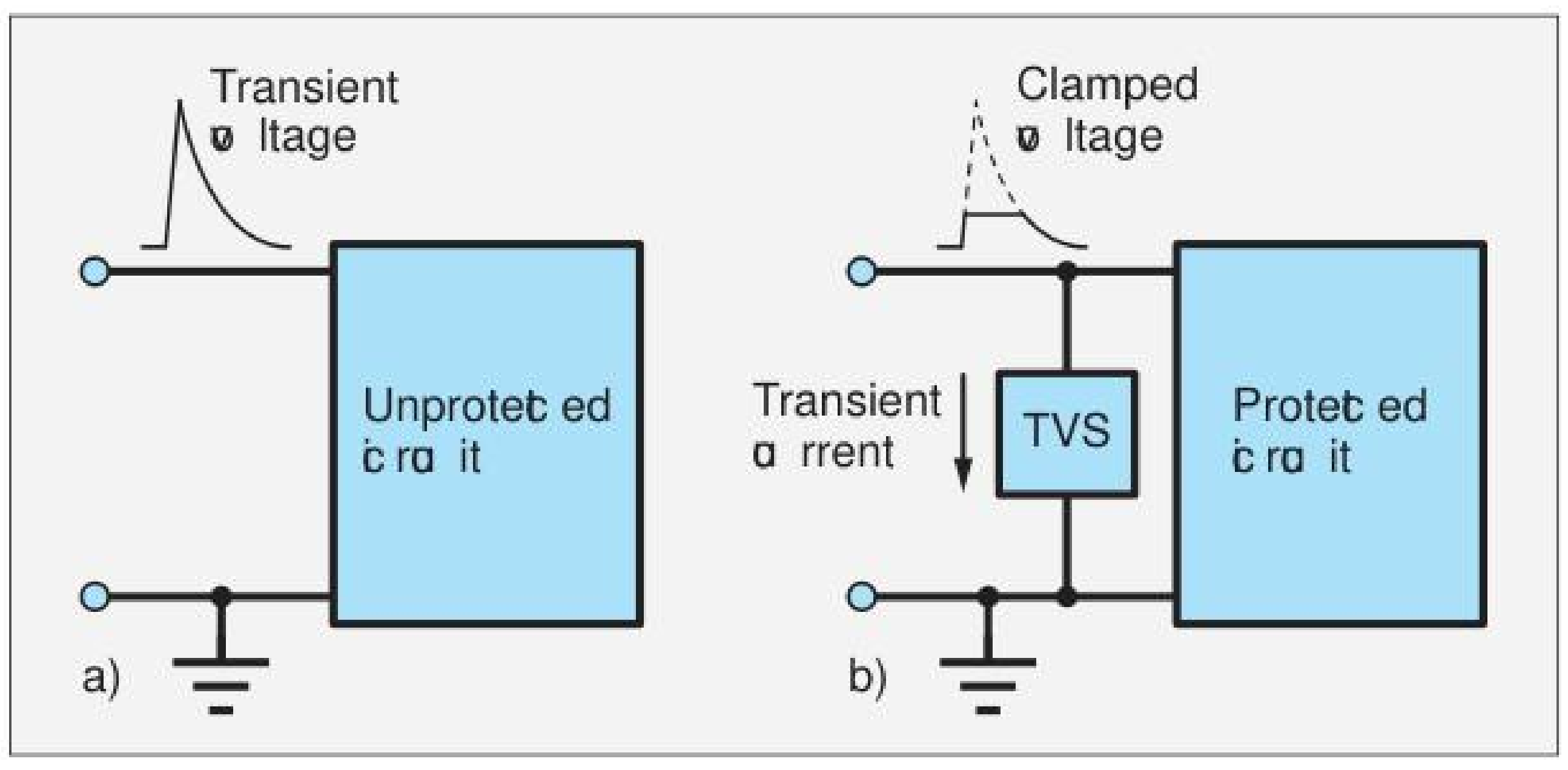


Fig.3. a) Circuit without suppression and b) Circuit with transient voltage suppression.

replace them is a positive temperature coefficient (PTC) device, also called a resettable fuse or polyswitch. Polymeric devices (PPTCs) are fabricated from a combination of a conducting particles and a non-conducting polymer. Heating caused by relatively high currents expands the polymer, separating the conducting particles and so increasing resistance very significantly above the switching (or trip) temperature – note that some leakage current will still flow. The resistance of ceramic PTCs varies with temperature as the properties of the material's grain boundaries change.

The circuit symbol for a PTC is shown in Fig.2 – this is similar to that used for thermistors in general, and varistors (see later). All these devices exhibit variable resistance characteristics in response to prevailing conditions. Note that sensor thermistor symbols may not have the short line at both ends of the diagonal shown in Fig.2 as this is not used consistently.

PTC resettable fuse are specified in terms of a hold current and trip current. The hold current is the maximum current under normal operating conditions – this varies with temperature. The trip current is the maximum current at which it will trip (again at a given temperature). Between the hold and trip currents the device can be in either the high or low resistance states. In the design process a PTC device is selected with a hold current above the maximum normal operating current and a trip current at or below the minimum current at which protection is needed. If the device trips, then after removal of the triggering condition, it will cool down and return to its conducting state after a certain amount of time.

Overvoltage protection

There are several devices used for overvoltage protection that are classed as transient voltage suppressors (TVS). They all exhibit changes in conduction with voltage. At relatively low voltages they are effectively open circuits but will have some leakage current, typically in units or tens of microamps. At higher voltages they become much more conductive, effectively clamping overvoltage spikes to a tolerable maximum voltage, thus preventing them from causing damage. To do this the TVS has to conduct a large transient current for the duration of the overvoltage. Time is an important factor – a TVS must respond quickly enough to catch the voltage spike before it causes damage.

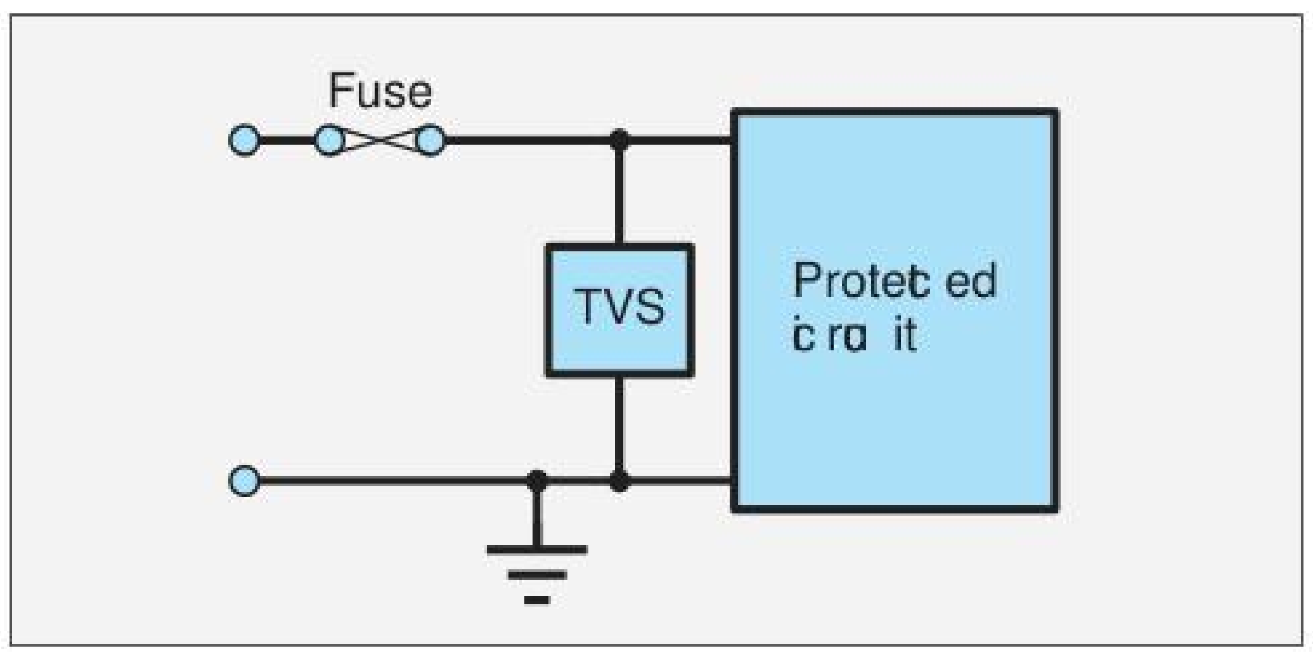


Fig.4. Combined TVS and fuse protection (PTC can be used in place of fuse).

Capacitance is typically the key parasitic characteristic of TVS devices. Adding capacitance to signal paths may impact frequency response, reduce input impedance, or affect switching speed, potentially degrading performance. TVS devices may exhibit capacitance which varies with voltage – this will introduce distortion in signal processing circuits. Leakage currents can also be problematic in precision circuits.

The basic TVS circuit concept is illustrated in Fig.3, which could apply to either a power supply connection or signal input. An EOS voltage transient is a rapid increase in voltage to a level which will damage a circuit. Fig.3 shows a typical transient waveform shape featuring a rapid rise followed by a slower exponential decay. Fig.3a shows the unprotected circuit which will be damaged by the transient. The circuit is protected by connecting a TVS across the source, as shown in Fig.3b. The TVS conducts above a certain voltage, typically exhibiting a clamping behaviour, which limits the voltage during the transient to a safe level – as shown in the waveform in Fig.3b. To do this, the TVS needs to conduct a large transient current and absorb the excess energy.

The combination of transient voltage and current, and the overvoltage duration determines the amount of energy that a TVS device must handle – it is the absorption of this energy by the TVS that protects the other circuitry. Poor choice of TVS for a given situation may result in its energy capabilities being exceeded, resulting in damage to the TVS. Protection may be lost, or in the worst case, the TVS may overheat or burn, resulting in further damage and potential fire hazards. As mentioned previously, fuses can be used in some situations to prevent damage to TVS devices where conditions may result in failure of the TVS (see Fig.4).

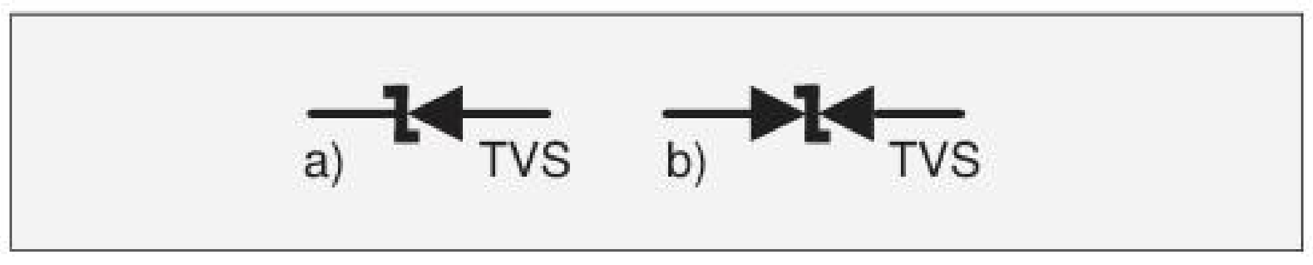


Fig.5. TVS diode symbols: a) unidirectional and b) bidirectional.

An alternative to voltage clamping is crowbar protection, in which the source is short circuited under EOS conditions. This is mainly applicable to power inputs, rather than signal inputs. Crowbars are typically implemented using a circuit (eg, thyristor plus trigger circuit) rather than an individual device. Crowbars are commonly used to cause fuses to blow, but alternatively may activate current-limiting behaviour in the source. Some TVS devices will fail as short circuits, causing a crowbar effect. If overcurrent protection is present this may be preferable to failing as an open circuit, which removes the protection.

TVS devices

TVS diodes are Zener or avalanche diodes designed for use in TVS applications and have similar voltage-current characteristics to standard Zener diodes. TVS diodes are optimised for TVS applications rather than voltage regulation; for example, they have a larger junction area to facilitate energy absorption. TVS diodes are used in reverse bias and undergo breakdown if a sufficient reverse voltage is applied, becoming significantly more conductive, absorbing energy and clamping the voltage. Zener or avalanche diodes have similar characteristics – the names reflect the different physical mechanisms involved in reverse breakdown. TVS diodes have a similar, or the same, symbol as a Zener diode (see Fig.5a). Two TVS diodes are often used in series to provide bidirectional protection, and these are available in single packages, with the symbol shown in Fig.5b.

Varistor protection

A varistor, or voltage-dependent resistor (VDR) is a device which has a resistance dependent on applied voltage. The most commonly used varistors are fabricated from ceramics and are known as metal-oxide varistors (MOVs). Like the ceramic PTVs mentioned earlier, the electrical behaviour of MOVs is related to the grain boundaries of the ceramic, which behave as a network of many diodes. They have the same circuit symbols as PTCs but can be distinguished by appropriate labelling (see Fig.6). Their current-voltage characteristics are similar to Zener diodes, except that the breakdown occurs at the same voltage for either polarity in a single device (see Fig.7). MOV voltage is often specified as the voltage at which they conduct 1mA – considered the lowest current at which they are performing

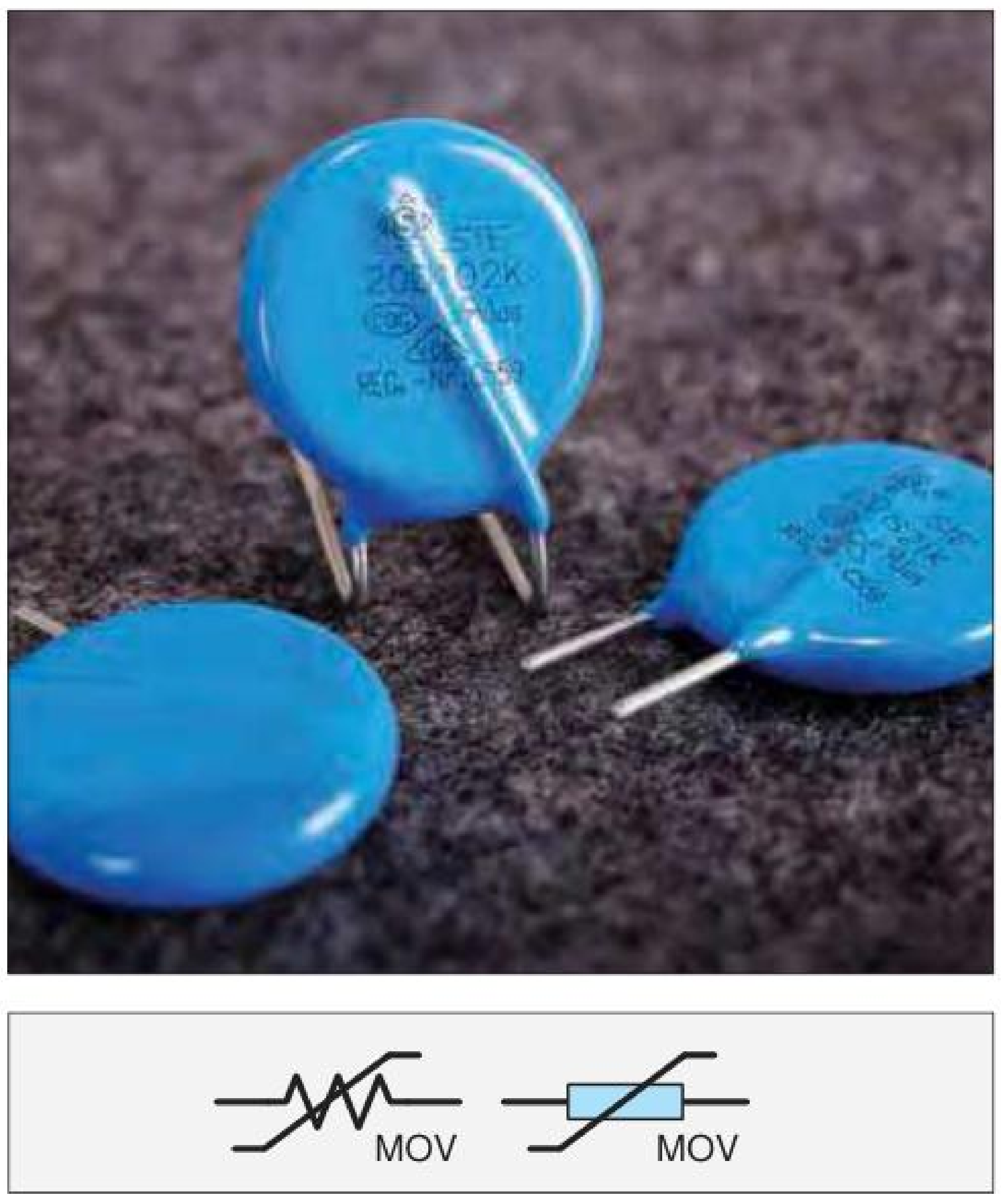


Fig.6. (above) Zinc metal-oxide varistors; (below) MOV circuit symbols.

clamping. Below this level, they are viewed as leakage rather than clamping currents. At higher currents a given MOV will have a higher clamping voltage.

Gas discharge tubes

Gas discharge tubes (GDT) contain two electrodes in a sealed device containing a gas which will ionise and conduct during a high voltage spike. Spark gaps are cruder versions of the same things – in which the air ionises if a sufficiently high voltage occurs. See Fig.8.

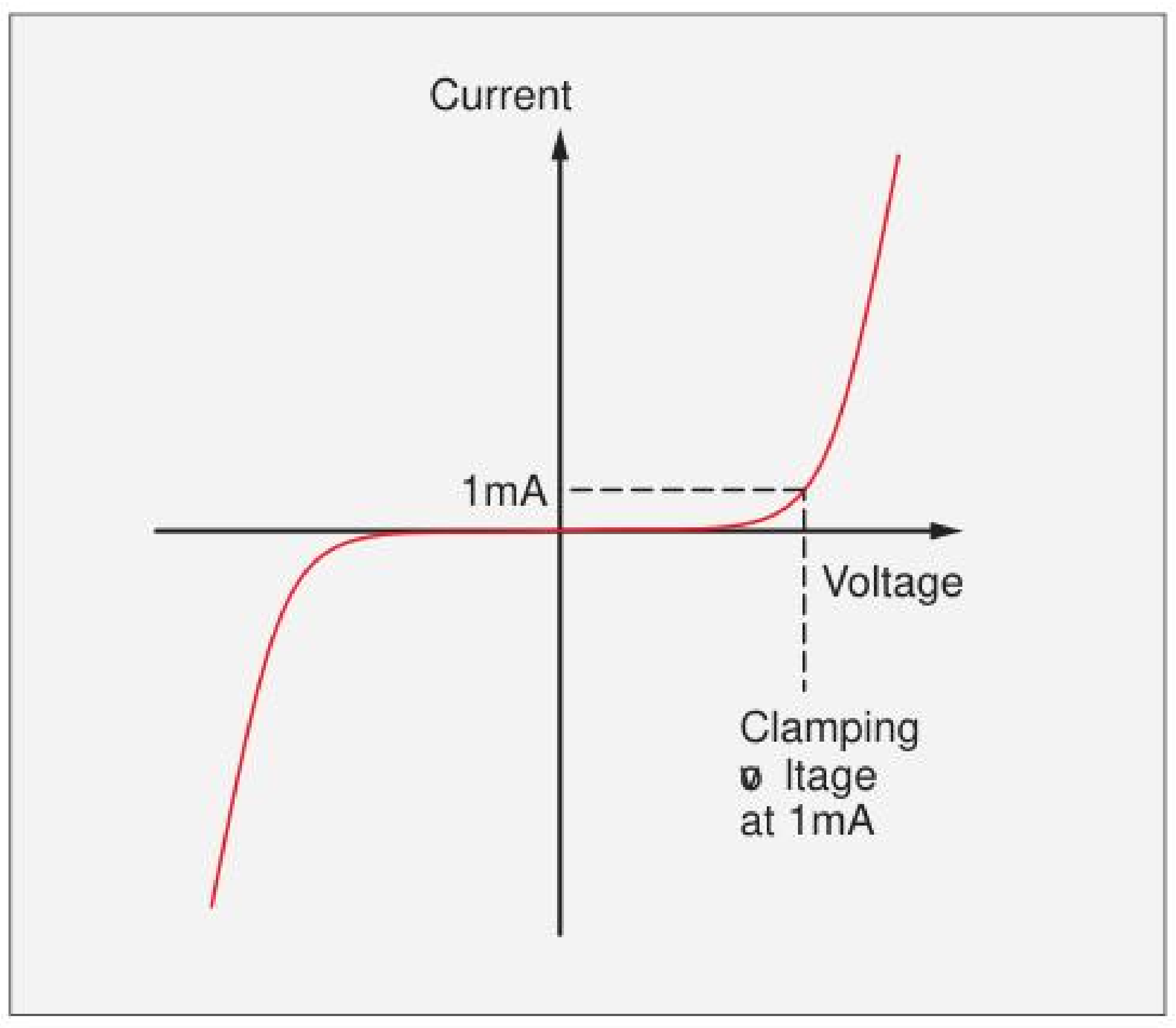


Fig.7. MOV basic characteristic curve.

Fig.8. Gas discharge tube (GDT) overvoltage suppressors from Eurotronix.

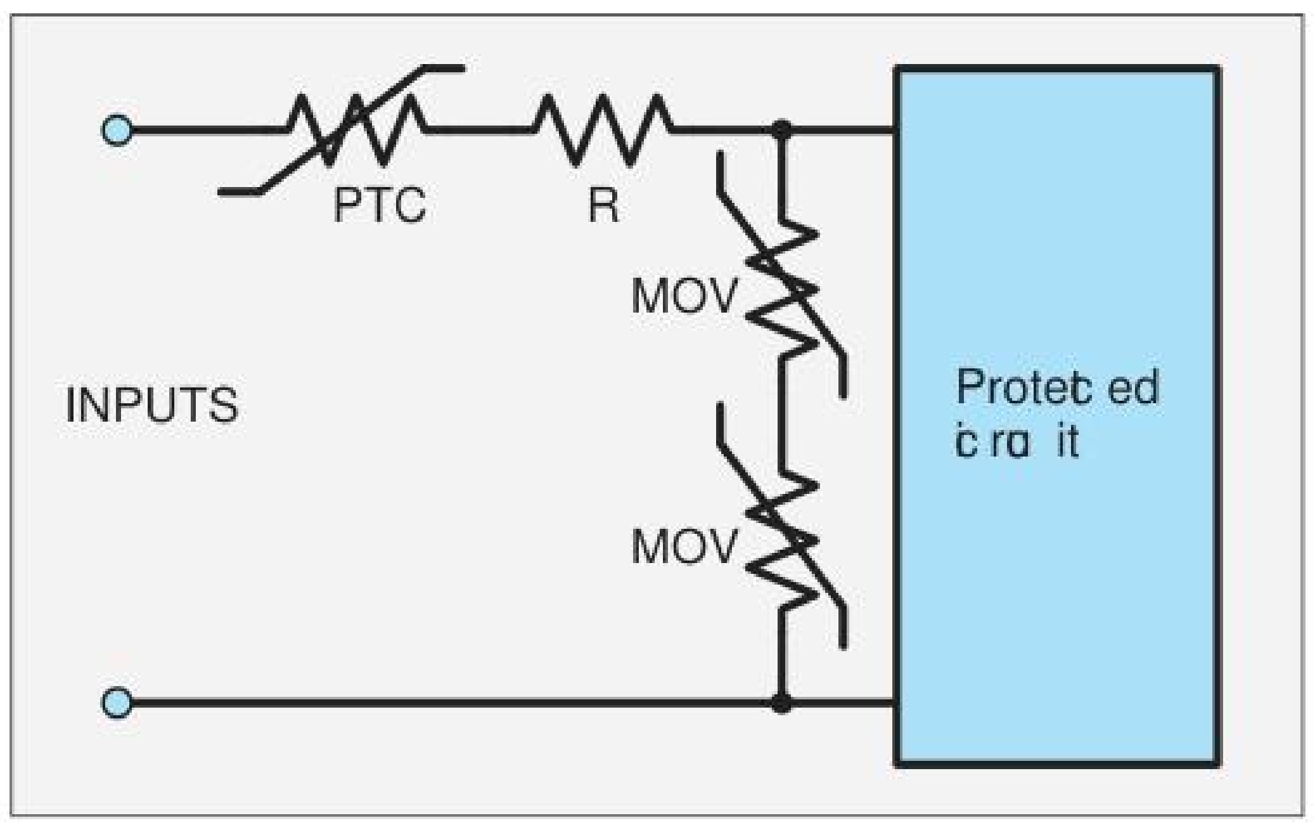


Fig.9. Example input protection circuit.

Protection circuits

Fig.9 shows an example input protection circuit, similar to the circuits that might be used in test instruments such as multimeters. The MOVs provide voltage clamping. More than one MOV is used in series – two are shown, but more could be used. Using multiple MOVs like this reduces the risk of arcing across individual devices and reduces the effective capacitance. During a voltage transient the MOVs will switch very quickly, but the PTC will take longer to respond and before it does a large transient current will flow. This is limited by the resistor, which needs to be of sufficiently high rating to handle the energy it will absorb during an overvoltage transient.

MOVs, TVSs and GDTs are typically used for protection at relatively high voltage levels (tens or hundreds of volts, or more). The switch-on of forward-biased standard diodes can also be used for overvoltage protection where protection is required at, or is appropriate to occur at, much lower voltages. The clamping voltage can be set to multiples of diode forward voltage (V_F = 0.6 to 0.7V for standard silicon diodes) by using diodes in series. An example is shown in Fig.10, which uses sets of five diodes in series to prevent the input exceedingly around 3.5V (5 × 0.7V) in either polarity. The circuit may also include a fuse or current limiting resistor. The same effect can be achieved with fewer diodes using a bridge rectifier across the inputs, with additional diodes connected across the bridge output.

For signal inputs to circuits using, for example, op amps, ADCs or microcontrollers, single diodes can be used to clamp input voltages to the supply rails (or more accurately one diode drop beyond the rail voltage). An example of such a circuit – an op amp unity-gain buffer with overvoltage protection is shown in Fig.11. Diode D1 conducts if the input goes higher than the positive supply voltage (V_P) by more than the turn-on voltage (forward drop, V_F). As the input voltage increases above V_S, V_F for D1 remains almost constant, clamping the voltage at the op amp input to $V_P + V_F$. Similarly, for negative input voltages, the op amp input is clamped at $-V_S - V_F$ by D2. The resistor R_L limits the current that can flow in the protection diodes, preventing them from being damaged. Standard diodes can be used in this type of circuit, but Schottky diodes (as shown in Fig.11) have a lower forward voltage. This clamps the inputs to a lower total voltage and prevents the op amp's internal ESD protection diodes from conducting, avoiding excessive current in these internal diodes (important because the ESD diodes are not designed to handle this situation).

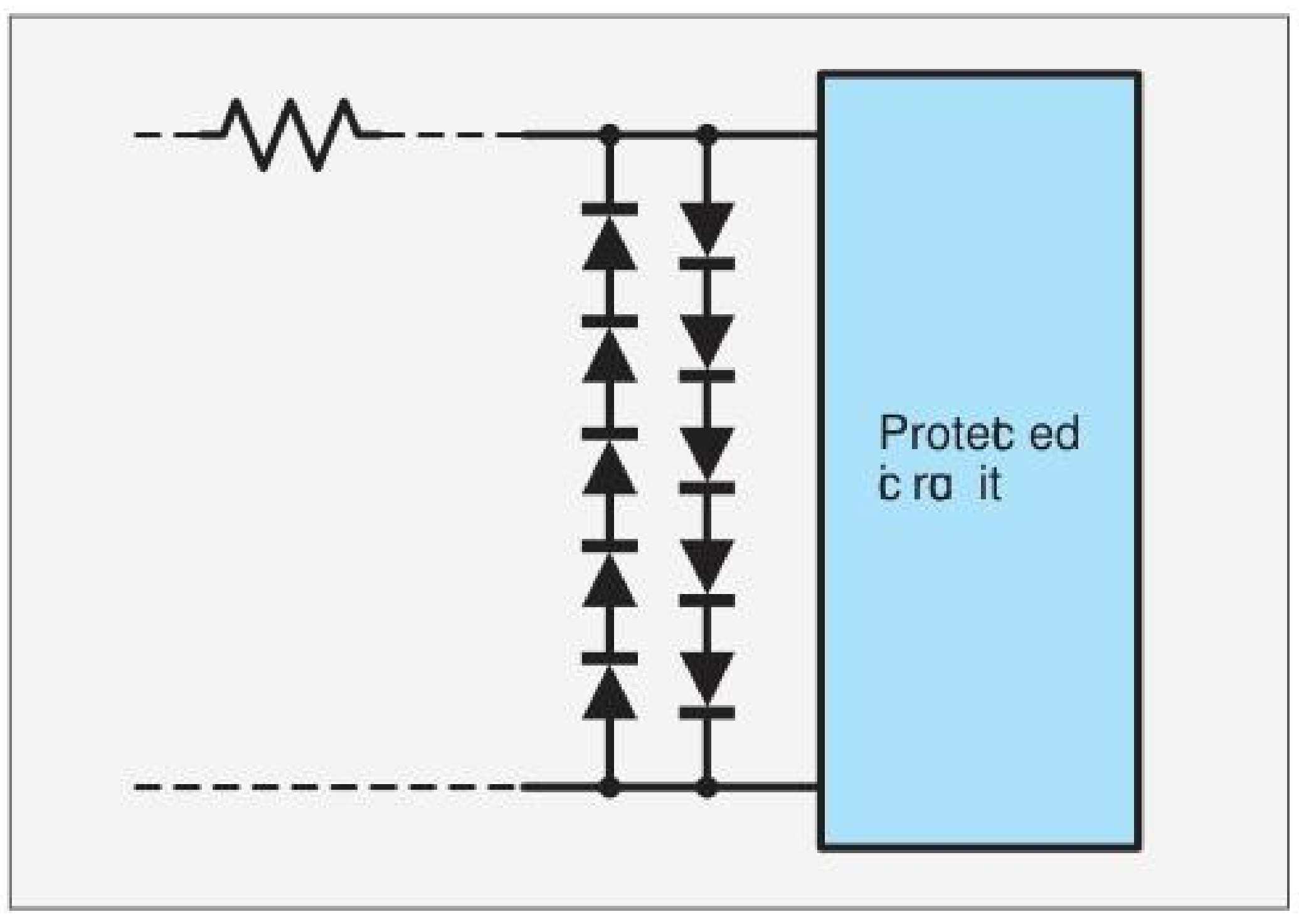


Fig.10. Using series diodes to clamp the input voltage.

With high EOS voltages the circuit in Fig.11 will cause an increase in supply rail voltage. This could damage the op amp or the regulator providing the power supply. To prevent this, the supply can be protected using TVS diodes, as shown in Fig.12. Leakage currents in input diodes in the circuits in Fig.11 and Fig.12 can degrade the performance of some high-precision circuits (during normal operation). To overcome this, some precision op amps have internal clamping circuits which provide protection with less impact on performance.

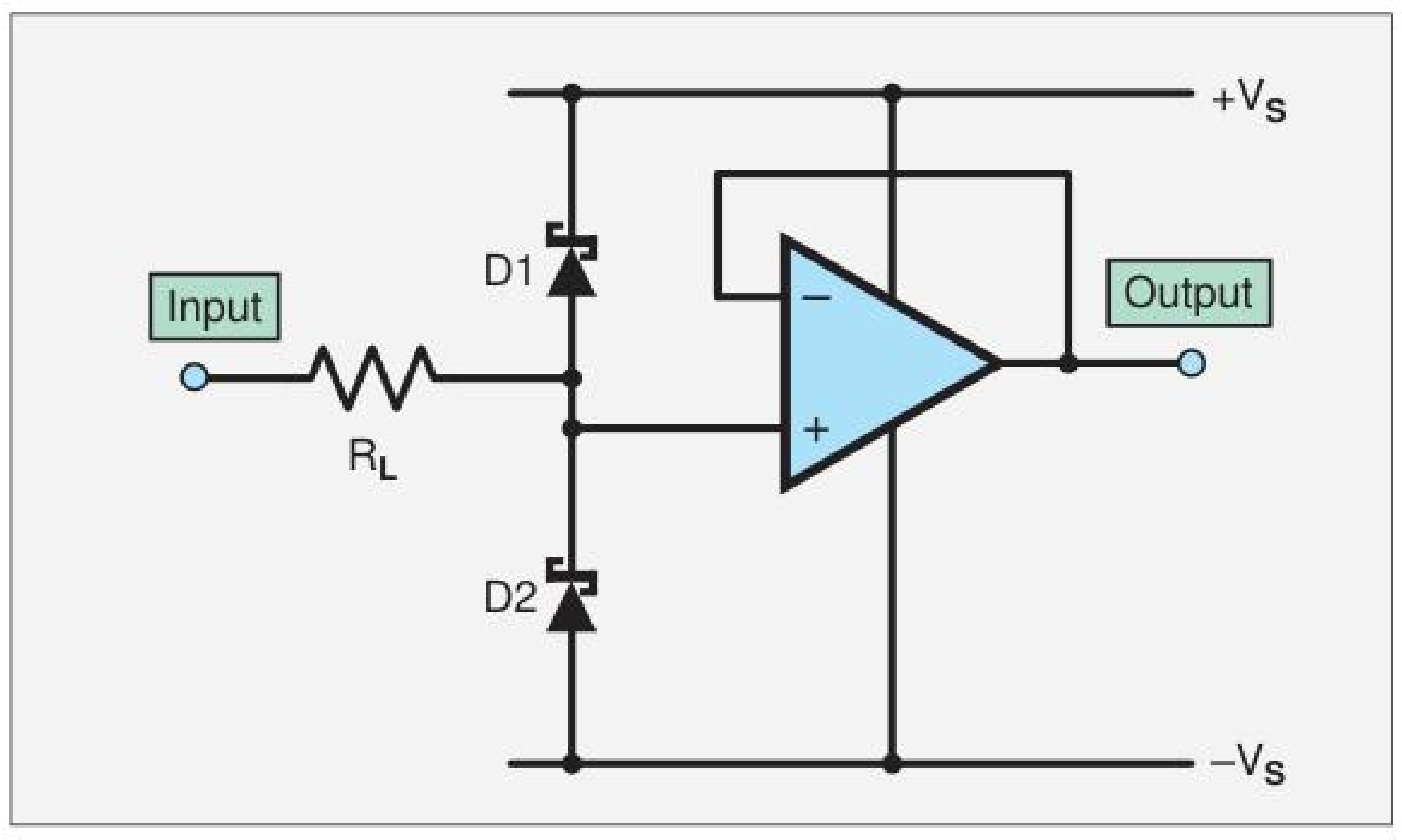


Fig.11. Example circuit: overvoltage protection using diode clamping.

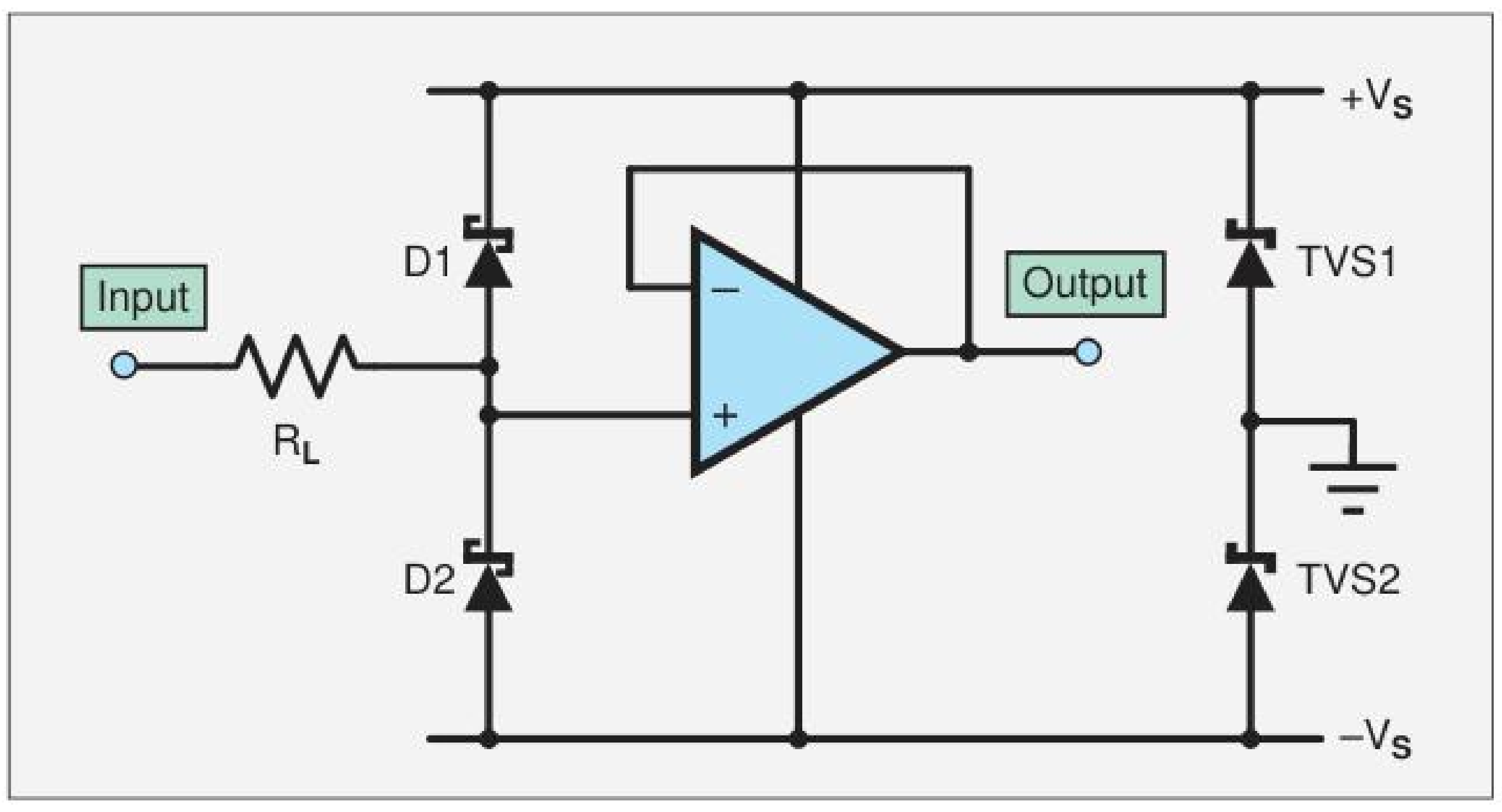


Fig.12. Adding TVS diodes to the circuit in Fig.10 provides additional protection.

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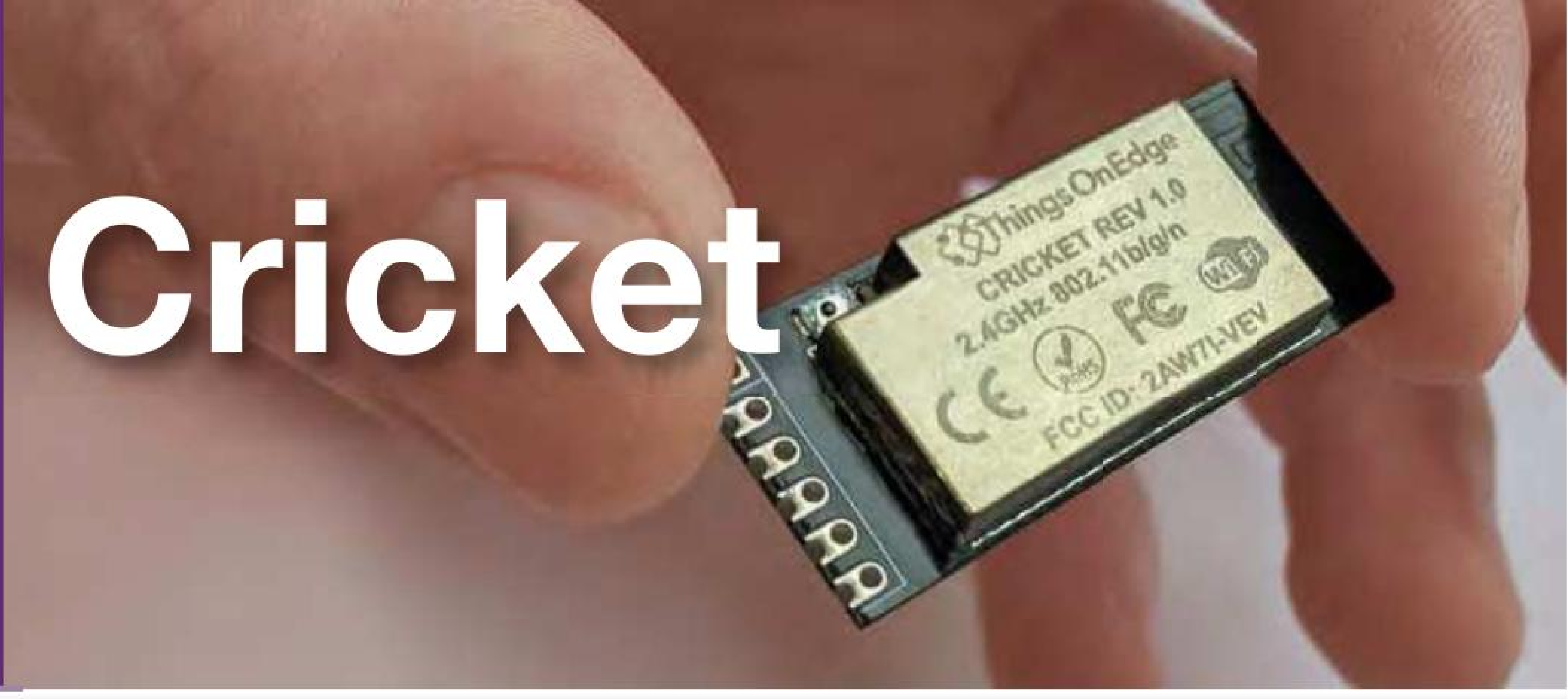


Khairul Alam – making the Internet of Things accessible for everyone

Part 2: Working with Node-RED and Raspberry Pi

In this issue, we will show how you can easily start to build the first parts of a local home automation system. We will make a battery-powered Wi-Fi sensor with an IoT Cricket module and integrate it with Node-RED – without writing code or programming. We will use the popular low-price Raspberry Pi (RPi) to host Node-RED in our local network. If you don't have an RPi, you can use FRED (**https://fred.sensetecnic.com/**) a cloud-based Node-RED server *without* subscription costs.

Last time, in *Part 1* (*PE*, June 2021) we showed how to use Cricket to make an IoT sensor node without any programming and integrate it with ThingSpeak for real-time visualisation of sensor data. ThingSpeak is a powerful tool for showing and analysing data, but for automation systems we need a more generic core system for data processing and integration to other systems. This is where Node-RED comes into play.

Node-RED

The aim this month is to expand our capabilities by setting up the chassis of a local home automation system using Node-RED, explaining how Node-RED is used as we progress. We are going to replicate what we achieved with ThingSpeak in *Part 1*, which will set us up for more advanced projects in the future. This project can be realised by makers at all skill levels. It may require some basic soldering, but it doesn't require any coding or programming. By the end of this project you'll have a solid understanding of how you can build your own local system and extend it by adding your own IoT end nodes.

Our system is going to be based on the MQTT communication protocol, which has been widely adopted in most IoT sensor nodes and home automation systems. We discussed MQTT protocol in detail in *Part 1*, so please refer to the June issue if you missed it. We will set up our own local MQTT broker for this project by installing an open-source Mosquitto MQTT broker on our RPi. Using a local broker gives us full control of the system without relying on the Internet.

Md. Khairul Alam is an Assistant Professor at the University of Asia Pacific, Dhaka, Bangladesh. He is an independent Cricket developer and does not work for Things On Edge.

Prerequisites

You will need the following hardware:

- RPi with Raspbian OS installed (we used ver. 3 but others should work)
- IoT Cricket Wi-Fi module
- 2 × AAA battery holder
- 2 × AAA batteries.

What is Node-RED?

Node-RED is a free and open-source graphical programming tool, primarily designed for the Internet of Things. It allows programmers of any level to interconnect physical things, cloud-based systems, databases and APIs to build applications using a web interface. It's great advantage is that it requires very little, if any, programming knowledge.

With Node-RED we can easily design our own automation system(s) by dragging and dropping nodes and connecting them. As the data flows through the system of connected nodes it triggers and performs actions defined by each node. One can compare Node-RED to a water system with various type of nodes, such as valves, power generators, heaters/coolers, pumps, tanks, outlets and so on. As the water flows it activates system nodes to use/modify (decision making) the water and generate the desired output(s) of the system.

For Node-RED, the 'water' is your data. As the data flows through the system, it passes in sequence from one connected node to another. Each node acts on the data and performs some actions and then passes it on. There are many types of nodes available which, for example, allow data to be:

- Filtered
- Visualised on custom dashboards
- Stored in database/filesystem
- Sent as notifications – eg, email or Twitter.

We also have many choices around integrating the data flow with other software and Internet services. Plus, a big advantage of Node-RED is that we can set up a system in our *local* network *without* relying on Internet service providers.

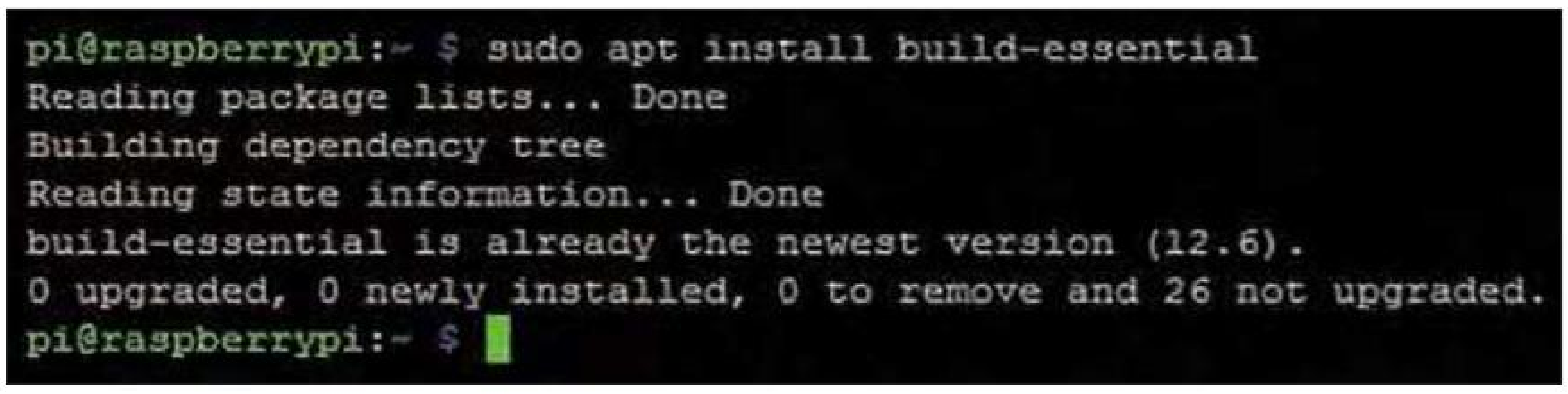
Node-RED allows developers to connect nodes (ie, predefined code blocks) to perform a task. The connected nodes – usually a combination of input nodes, processing nodes and output nodes – are 'wired' together to make up an application program called a 'flow'. There are lots of nodes available to perform simple and complex tasks, including web access, Twitter posting, email, HTTP, UDP, MQTT, control of GPIO ports, displaying a graphical dashboard and more. Also, many built-in nodes allow you to install third-party nodes, just like we install third-party libraries in Arduino.

Note that although we will focus on the graphical nature of Node-RED, it allows you a lot of functional control (similar to custom functions in a text language) through JavaScript. JavaScript is the programming language that is underlying Node-RED.

That's enough background to Node-RED. Now let's learn how we can use it to make our own system; and the best way to learn is by doing it ourselves. There are plenty of resources available on the Internet (Google, of course, is your friend here). However, this month's project will provide a basic introduction of how to set it up on an RPi and integrate devices built with the Cricket IoT Wi-Fi module into your system.

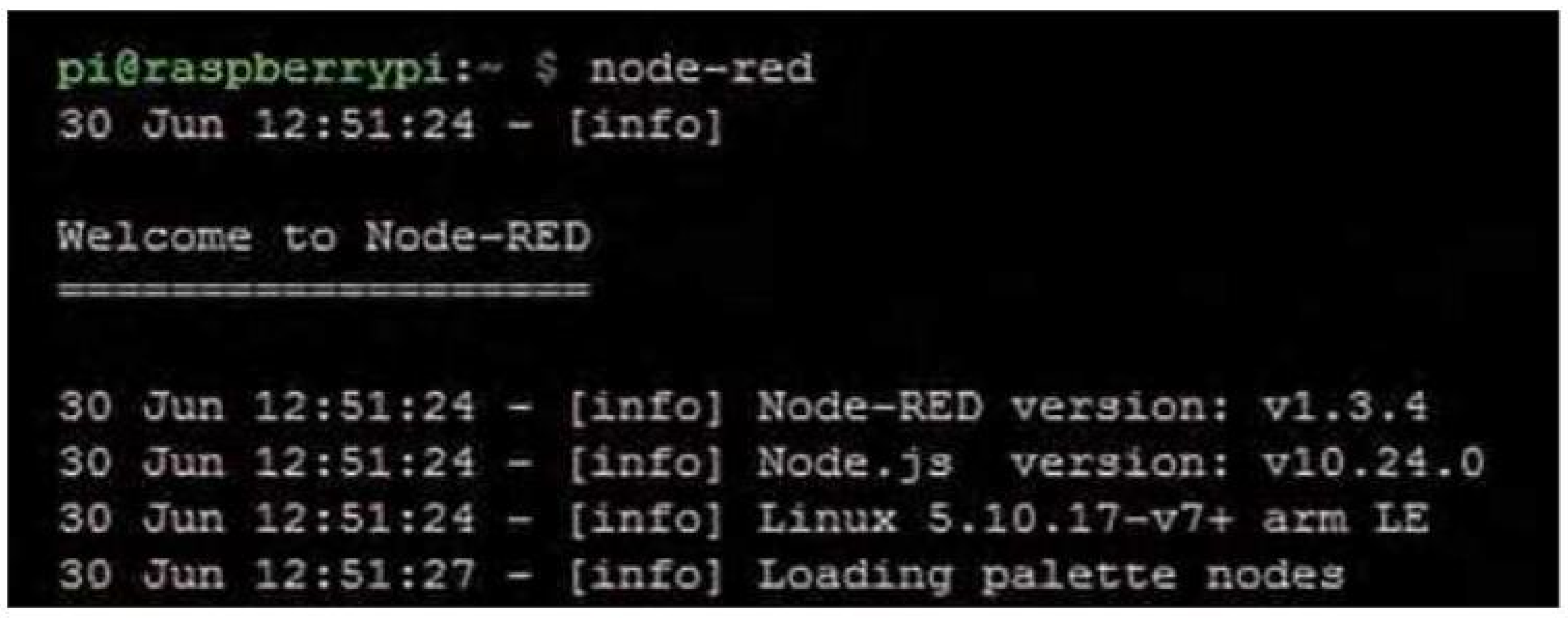
Installing Node-RED on Raspberry Pi

Before starting, I am assuming you have access to an RPi with the Raspbian OS installed and already have some experience working with it. If you have yet to install the OS then you can find



```
pi@raspberrypi:~ $ sudo apt install build-essential
Reading package lists... Done
Building dependency tree
Reading state information... Done
build-essential is already the newest version (12.6).
0 upgraded, 0 newly installed, 0 to remove and 26 not upgraded.
pi@raspberrypi:~ $
```

Fig.1. Installing 'build-essential' before installing Node-RED on the RPi.



```
pi@raspberrypi:~ $ node-red
30 Jun 12:51:24 - [info]

Welcome to Node-RED
===================

30 Jun 12:51:24 - [info] Node-RED version: v1.3.4
30 Jun 12:51:24 - [info] Node.js  version: v10.24.0
30 Jun 12:51:24 - [info] Linux 5.10.17-v7+ arm LE
30 Jun 12:51:27 - [info] Loading palette nodes
```

Fig.2. Part of the terminal output when Node-RED starts in RPi.

detailed instructions on installing the operating system image on RPi here: **https://bit.ly/pe-oct21-iot1**

You can find the most up-to-date official instructions on installing Node-RED on RPi here: **https://bit.ly/pe-oct21-iot2**

Note that if you downloaded and installed the latest RPi OS then it's possible Node-RED is already preinstalled. You can check this at the terminal with the command:

```
node-red --help
```

Before we start installing, it's good practice first to update the system components using the following terminal commands:

```
sudo apt-get update
sudo apt-get upgrade
```

Then, run the following command to install 'build-essential':

```
sudo apt install build-essential
```

Note that you may get the result shown in Fig.1 if it's already the newest version. After that, install Node-RED by running the following command in the terminal. This command will download and run a script provided by Node-RED authority to install Node.js, npm and Node-RED onto an RPi.

```
bash <(curl -sL https://raw.githubusercontent.
com/node-red/linux-installers/master/deb/
update-nodejs-and-nodered)
```

The 'npm' stand for 'node package manager' and is useful for the JavaScript programming language that Node-RED is built on. npm will enable you to install additional modules for use with Node-RED. Before the script begins to run you will be asked two questions. Just type 'y' and press ENTER for both to continue.

After installing Node-RED you need to start it. There are different ways to do this, but the easiest is to run the following command, which will produce the terminal output shown in Fig.2: `node-red`

This works fine on an RPi with at least 2GB of RAM. For earlier RPi models with limited RAM, it's better to specify the amount of RAM, as follows:

```
node-red-pi --max-old-space-size=256
```

Regardless of which method you choose, the Node-RED service will begin within a few seconds, and indicate that it is running on 'localhost' with the default port 1880.

Now, you can open the Node-RED web editor by going to the following URL in your favourite web browser from any computer/phone connected to the same network as the RPi:

```
http://{your_pi_ip-address}:1880
```

To obtain the IP address of your RPi use this command:

```
hostname -I
```

If everything works correctly, you should now be greeted by the screen shown in Fig.3.

It would be convenient to have Node-RED running permanently as a service in the background so that whenever we start our RPi the Node-RED system automatically launches at boot time. All we need to do this is execute the following command:

```
node-red-start
```

The above command starts the Node-RED service and displays its log output. Pressing `Ctrl-C` or closing the window does not stop the service; it keeps running in the background. Now enable the service to autostart by running the command:

```
sudo s0ystemctl enable nodered.service
```

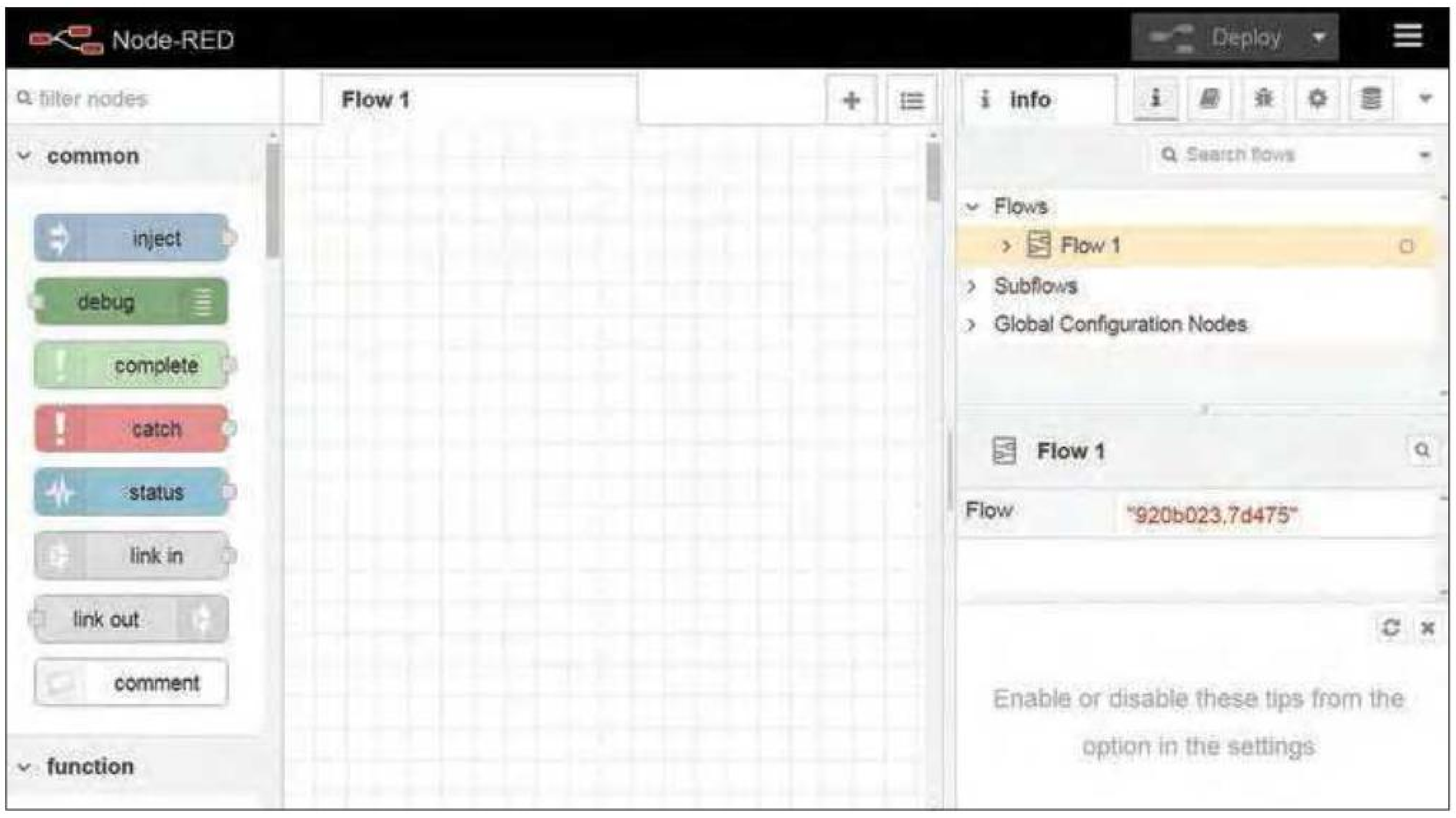


Fig.3. View of the Node-RED workspace.

That's it. Now, whenever we boot RPi the Node-RED service will automatically start.

Getting started with Node-RED

Now that we have Node-RED up and running on our RPi, let's start with a very simple example before going on to our main project. As we've already discussed, a program created in Node-RED is called a 'flow', and it's created by wiring multiple nodes together. There are three main types of nodes:

1. Input nodes (eg, inject)
2. Processing nodes (eg, function)
3. Output nodes (eg, debug).

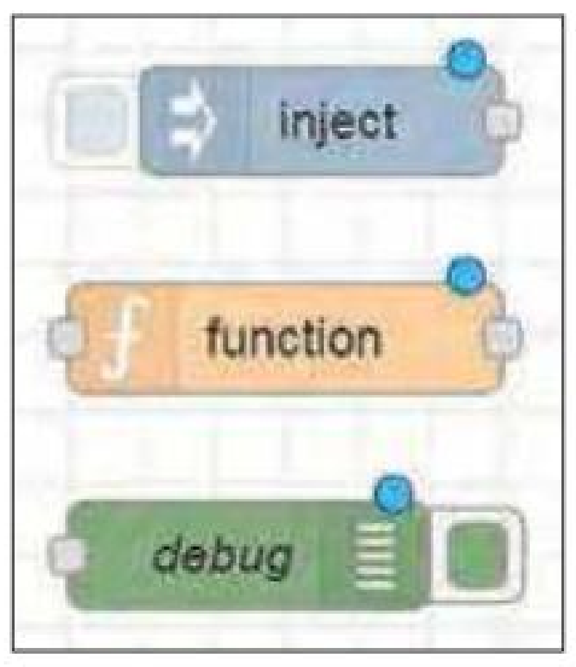


Fig.4. The three basic nodes.

Three example nodes are shown in Fig.4. Input nodes allow you to input data into a Node-RED program or flow. They have at least one output endpoint represented by a small grey square on their right side. Output nodes are used to send data outside and have a single endpoint on their right side. Processing nodes allow us to process data. They have an input endpoint and one or more output endpoints. In a Node-RED flow, messages pass between nodes, moving from input nodes, through processing nodes to output nodes.

Let's build a 'Hello World' type of flow to see how simple it is to use the Node-RED UI to build and deploy (run) flows. (Note

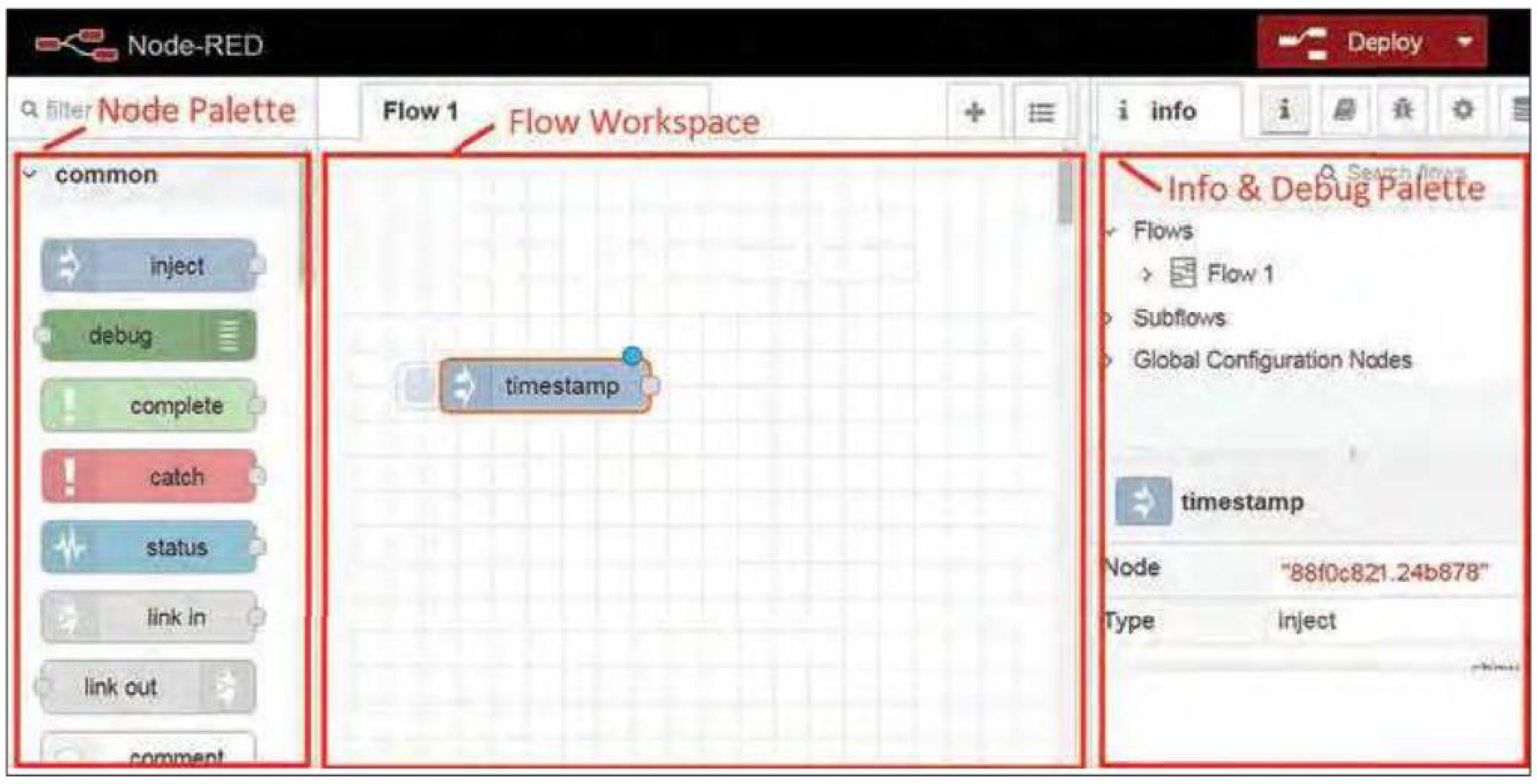


Fig.5. Three parts of Node-RED environment.

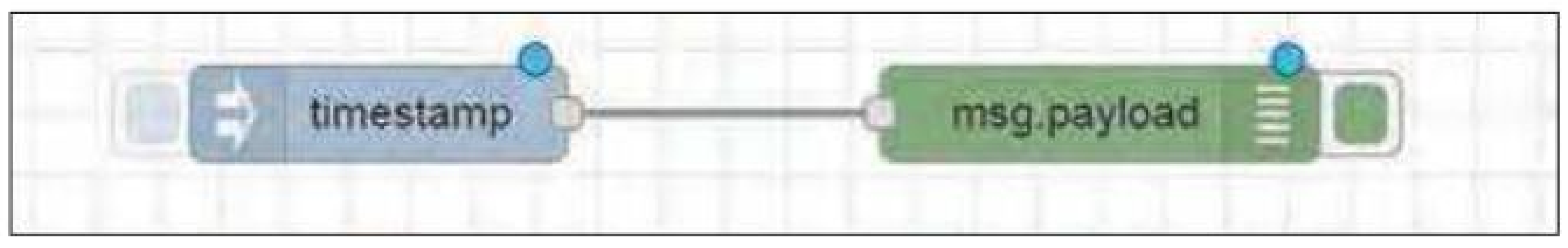


Fig.6. The Hello World flow.

that in this case we won't actually print out the words 'Hello World' – we will say 'hello' by printing a timestamp.) To do this we will use an inject node to input a timestamp into the flow, which is consecutively wired to a debug node for printing out the timestamp on the screen.

Since this is our first flow build, we'll explain each step with a screenshot. Our first node will be the inject node. This is used to generate input for our flow. Drag and drop an inject node (from the node palette on the left) into the flow workspace (centre), and then look at the info tab (on the right) where you'll see the attributes of the node. Fig.5 shows the node palette, workspace with added inject node and debug palette. In the workspace inject node you can see a timestamp because by default a timestamp input is set – the current time in milliseconds since 1 January 1970.

You will see a small grey square on the right side of the node where we attach a wire that routes an output message to the next node in the flow. To sense the output from the inject node let's add a debug node by dragging one from the node palette to the workspace. There are now two nodes in the workspace and we need to wire these together. To do that, click on the grey output point for the inject node, holding the mouse button down, drag towards the debug node. An orange wire appears, which you can then attach to the grey input point on the debug node. The complete flow will look like Fig.6.

After building the 'Hello World' flow we need to 'deploy' it to see the output. Click the Deploy button (top right) and you will see a pop-up saying the flow has been successfully deployed (see Fig.7).

Now click on the left tab on the inject node and you will see the timestamp (a long number) appear in the debug pane on the right-hand side (see Fig.8).

Congratulation, you created and deployed your first flow, and we are ready to move on to the next step. Our goal is to receive the temperature and battery level from the Cricket using MQTT communication protocol and display the data on a graphical web dashboard. Node-RED will be used to receive MQTT data, make a graphical dashboard and display the result in real time. Let's take this in stages.

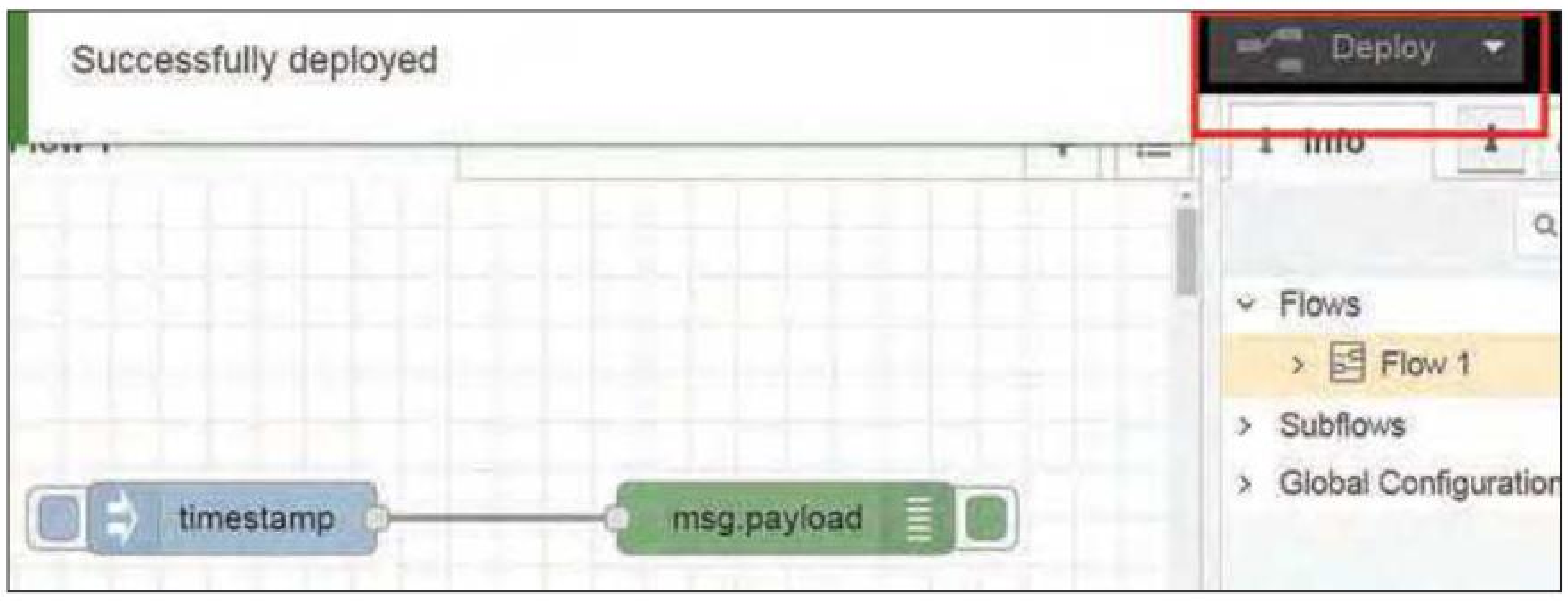
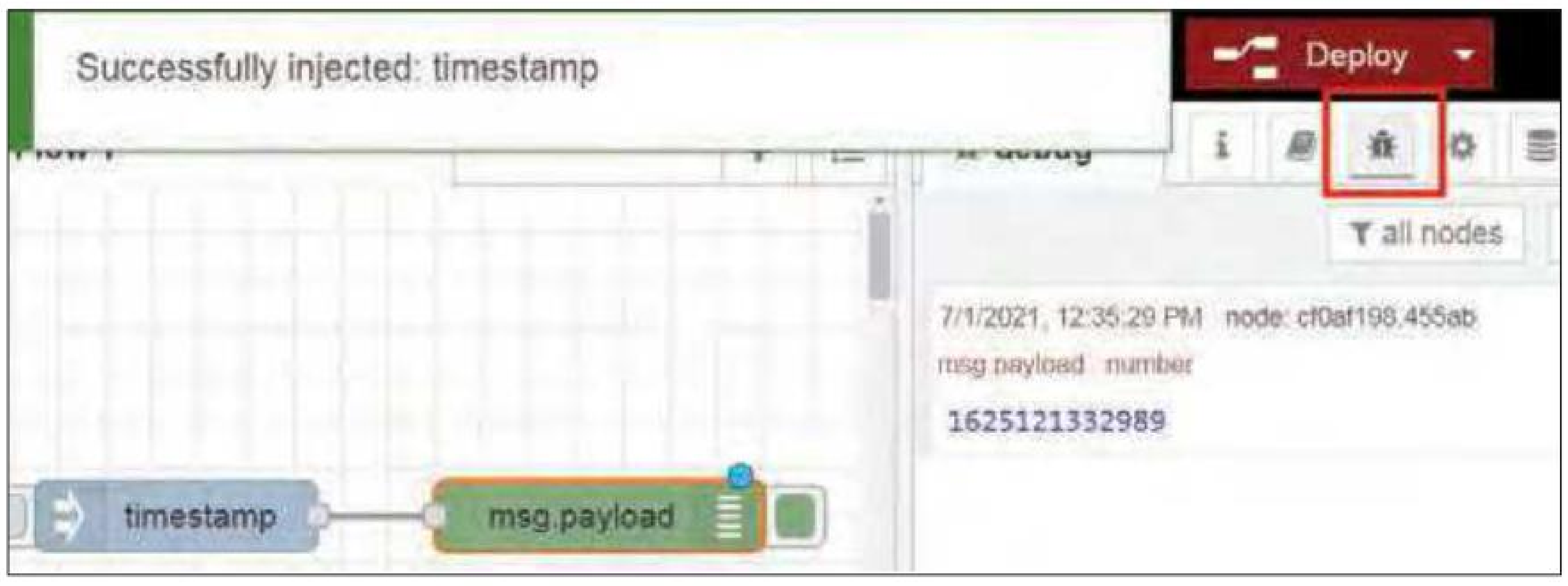

Successfully deployed

Fig.7. Deploying the flow.


Successfully injected: timestamp

7/1/2021, 12:35:29 PM node: cf0af198.455ab
msg.payload : number
1625121332989

Fig.8. Output of the flow.

MQTT in brief

MQTT is a lightweight messaging protocol designed for resource-constrained devices with low bandwidth. MQTT consists of a message broker and a number of clients. The broker is a server that receives all messages from the clients and then routes those messages to relevant destination clients. A client is anything that can interact with the broker to send and receive messages using a specific topic. Every MQTT broker (local or cloud) has a host address and a port number, which is 1883 for non-encrypted communication. Clients connected to the same broker can communicate with each other. To know more about MQTT please refer to page 44 of the June issue.

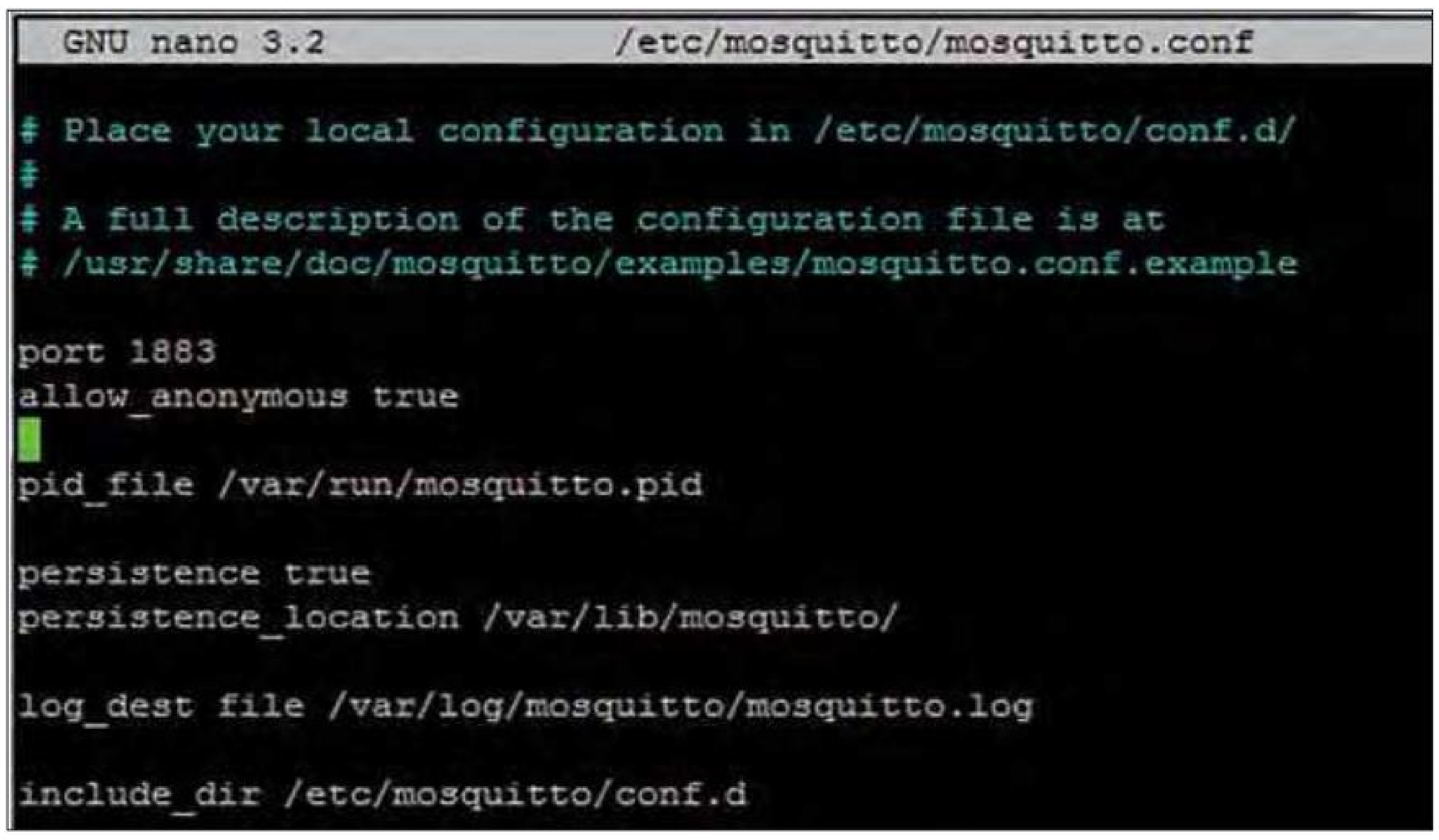
In this project we are going to set up our own local MQTT broker on our RPi running Node-RED.

Installing an MQTT broker on Raspberry Pi

First, with Node-RED running, we will install the open-source Mosquitto MQTT broker on our RPi. Mosquitto is lightweight and is suitable for use on all devices from low-power, single-board computers to full servers. To Install Mosquitto broker, open a terminal and type the following command:

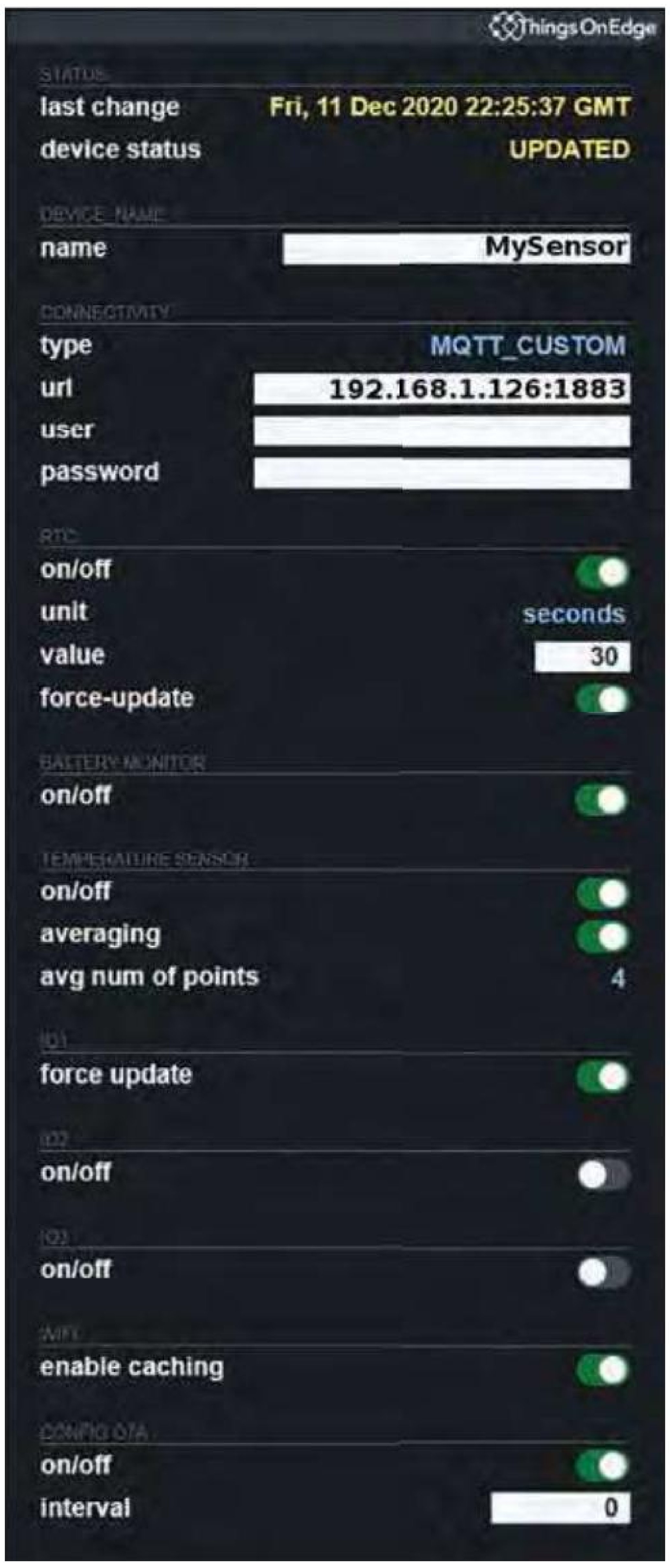
```
sudo apt-get install mosquitto -y
```

To configure Mosquitto broker open the config file using a text editor (eg, nano or vi):



```
  GNU nano 3.2              /etc/mosquitto/mosquitto.conf

# Place your local configuration in /etc/mosquitto/conf.d/
#
# A full description of the configuration file is at
# /usr/share/doc/mosquitto/examples/mosquitto.conf.example

port 1883
allow_anonymous true

pid_file /var/run/mosquitto.pid

persistence true
persistence_location /var/lib/mosquitto/

log_dest file /var/log/mosquitto/mosquitto.log

include_dir /etc/mosquitto/conf.d
```

Fig.9. Editing the RPi config file.



STATUS
last change: Fri, 11 Dec 2020 22:25:37 GMT
device status: UPDATED

DEVICE_NAME
name: MySensor

CONNECTIVITY
type: MQTT_CUSTOM
url: 192.168.1.126:1883
user
password

RTC
on/off ●
unit: seconds
value: 30
force-update ●

BATTERY MONITOR
on/off ●

TEMPERATURE SENSOR
on/off ●
averaging ●
avg num of points: 4

IO1
force update ●

IO2
on/off ○

IO3
on/off ○

WIFI
enable caching ●

CONFIG OTA
on/off ●
interval: 0

Fig.10. Configuration of the Cricket.

```
sudo nano /etc/mosquitto/
mosquitto.conf
```

Add the following lines at the top and save:

```
port 1883
allow_anonymous true
```

Fig.9 should make this clear. Now enable the broker and allow it to autostart on boot up using the following command:

```
sudo systemctl enable mosquitto.
service
```

Finally, restart RPi to apply changes:

```
sudo reboot
```

That's it! Our MQTT broker is up and running now. You can test the installation with the command:

```
mosquitto –v
```

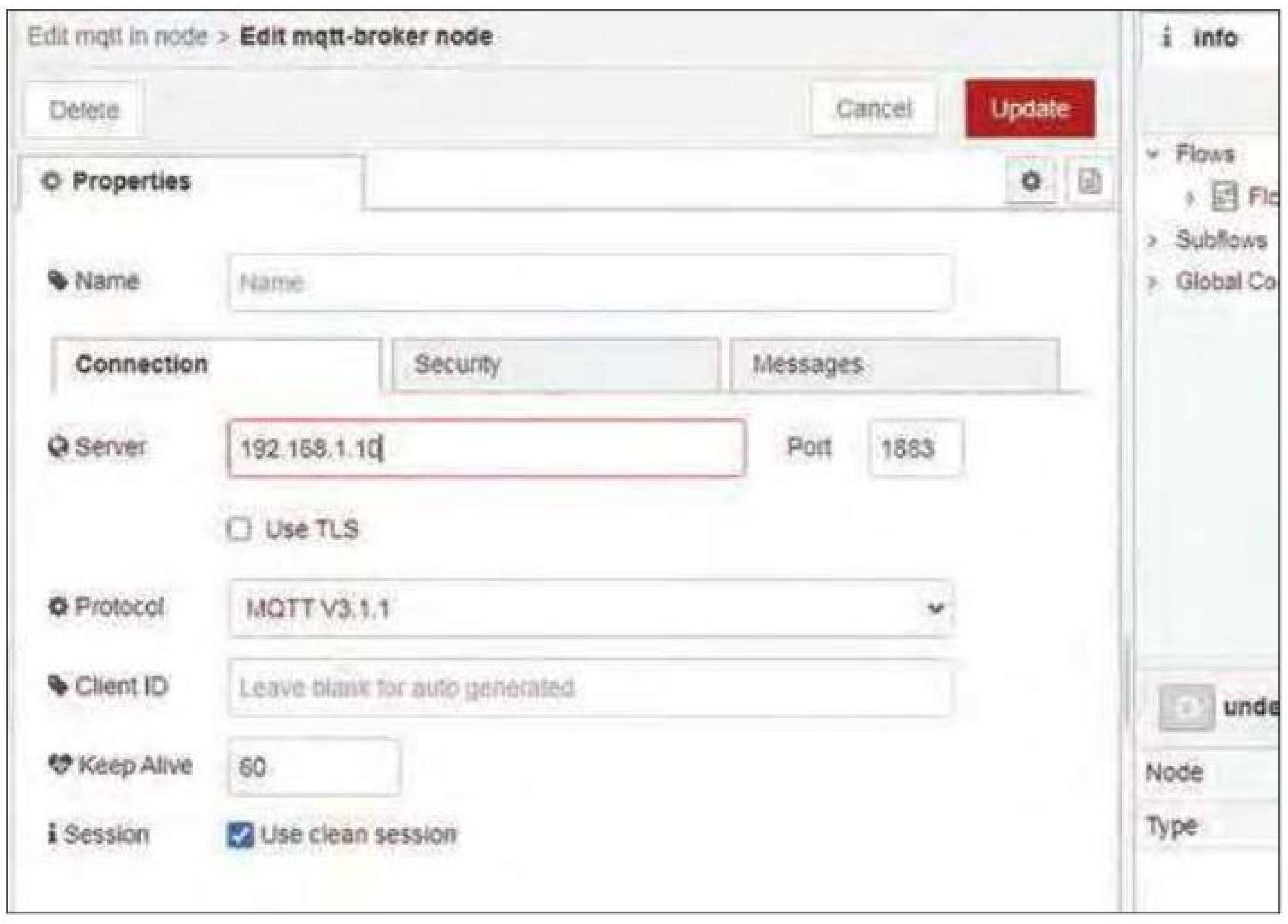
This will return the Mosquitto version that is running on your RPi. For more information on how to install Mosquitto MQTT broker on an RPi, visit: **https://bit.ly/pe-oct21-iot3**

Soon, we will start building a flow in Node-RED to receive MQTT messages using an MQTT node. But before that we need to configure a Cricket to send data over MQTT to our system.

Configuring Cricket to send sensor data via MQTT

The Cricket IoT module transmits the temperature and battery voltage level to the `/SERIAL/temp` and `/SERIAL/batt` topics respectively, where `SERIAL` is the unique serial number of the Cricket module. Before starting the flow, let's find the serial number of the Cricket module and configure it to transmit temperature (using the built-in temperature sensor) and battery level through MQTT. (We won't discuss the whole configuration process here. For more configuration details refer to *Part 1* in the June 2021 issue.)

Cricket comes with a built-in temperature sensor (or, if you want, you can add any other external analogue sensor to its IO2 pin). We need to configure it to send this temperature value via MQTT. We'll configure it to send the temperature every 30 seconds to our system. Since it's running on battery power we can place and monitor the temperature anywhere at home or even outside in the garden.



Name: Name
Server: 192.168.1.10
Port: 1883
☐ Use TLS
Protocol: MQTT V3.1.1
Client ID: Leave blank for auto generated
Keep Alive: 60
Session: ☑ Use clean session

Fig.12. Configuring mqtt server.

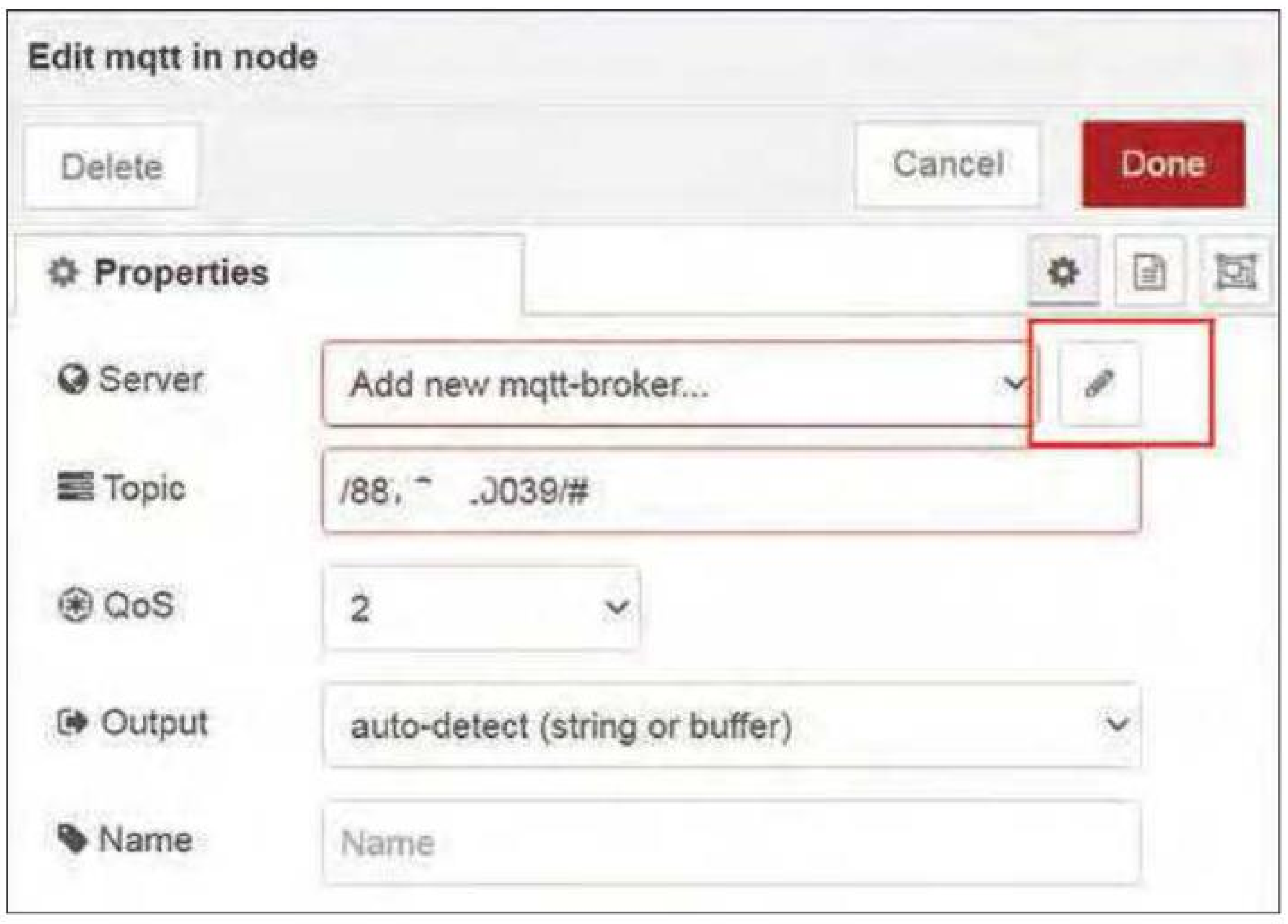
In order to configure Cricket we need to attach the batteries and press the built-in button for five seconds until the LED starts flashing fast. Then connect to the 'toe_device' hotspot from any device with web browser capabilities. Set your Wi-Fi credential and note down the SN (serial) from the INFO panel. The setting should be as shown in Fig.10. (Note: you need to adjust the IP address in the 'url' box to match your RPi.)

We set the Cricket to wake up every 30 seconds because that is a good interval for experimenting with data and setting up this project. However, once you are done with this project, please change it to an interval that makes more sense, for example, once an hour or more. Your batteries will thank you!

Now you can exit from the configuration mode and the device is ready. Cricket is sending data to our local MQTT broker every 30 seconds, so next we will make a flow to receive the data from the broker and show it in a graphical dashboard.

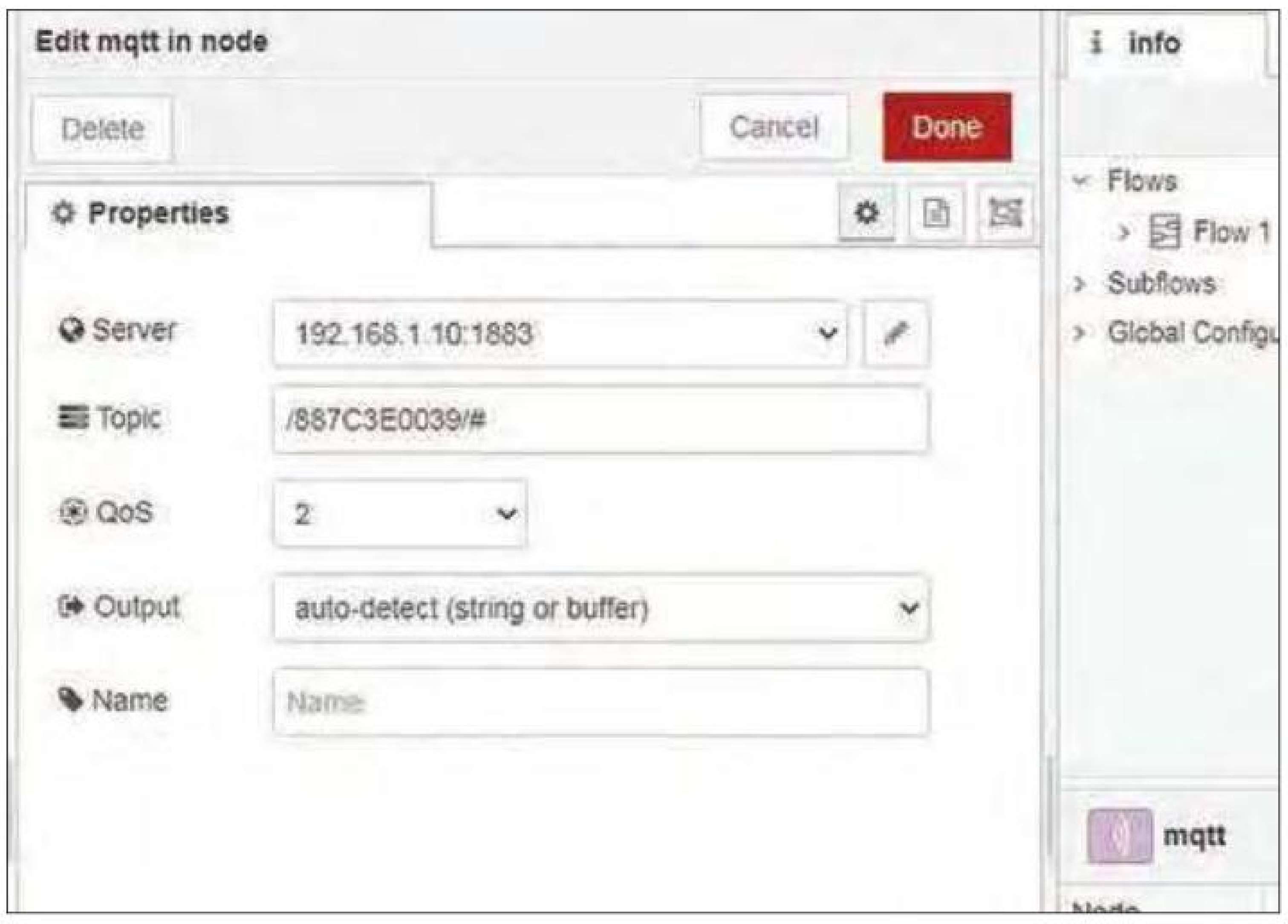
Receiving an MQTT message in Node-RED

To receive an MQTT message, drag and drop an 'mqtt in' node into the workspace. Then double click to configure it for Cricket and our local MQTT broker. Enter your



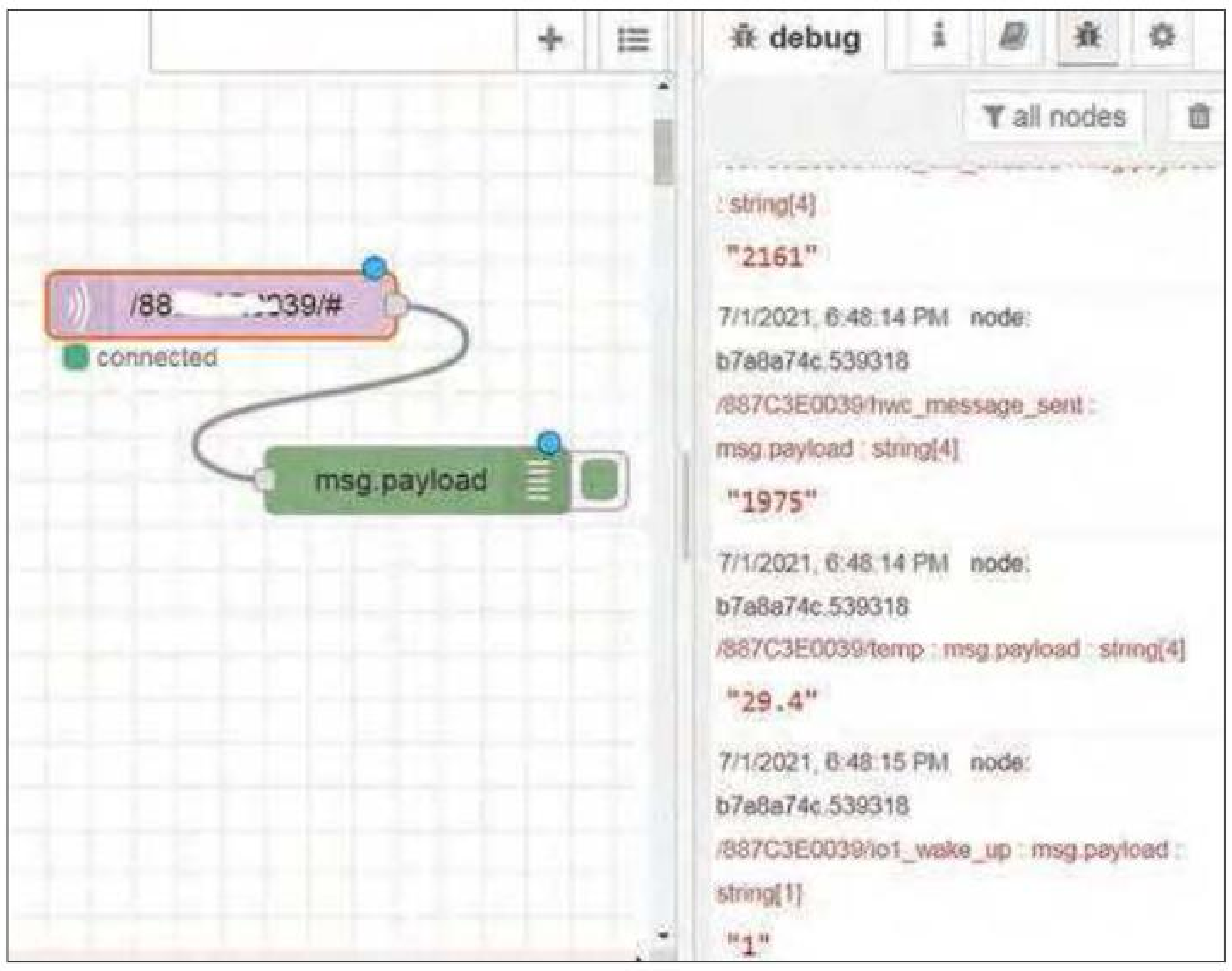
Server: Add new mqtt-broker...
Topic: /88,   .0039/#
QoS: 2
Output: auto-detect (string or buffer)
Name: Name

Fig.11. mqtt in node topic configuration.



Server: 192.168.1.10:1883
Topic: /887C3E0039/#
QoS: 2
Output: auto-detect (string or buffer)
Name: Name

Fig.13. mqtt server and topic added.



```
: string[4]
"2161"
7/1/2021, 6:48:14 PM  node:
b7a8a74c.539318
/887C3E0039/hwc_message_sent :
msg.payload : string[4]
"1975"
7/1/2021, 6:48:14 PM  node:
b7a8a74c.539318
/887C3E0039/temp : msg.payload : string[4]
"29.4"
7/1/2021, 6:48:15 PM  node:
b7a8a74c.539318
/887C3E0039/io1_wake_up : msg.payload :
string[1]
"1"
```

Fig.14. MQTT messages received in Node-RED.

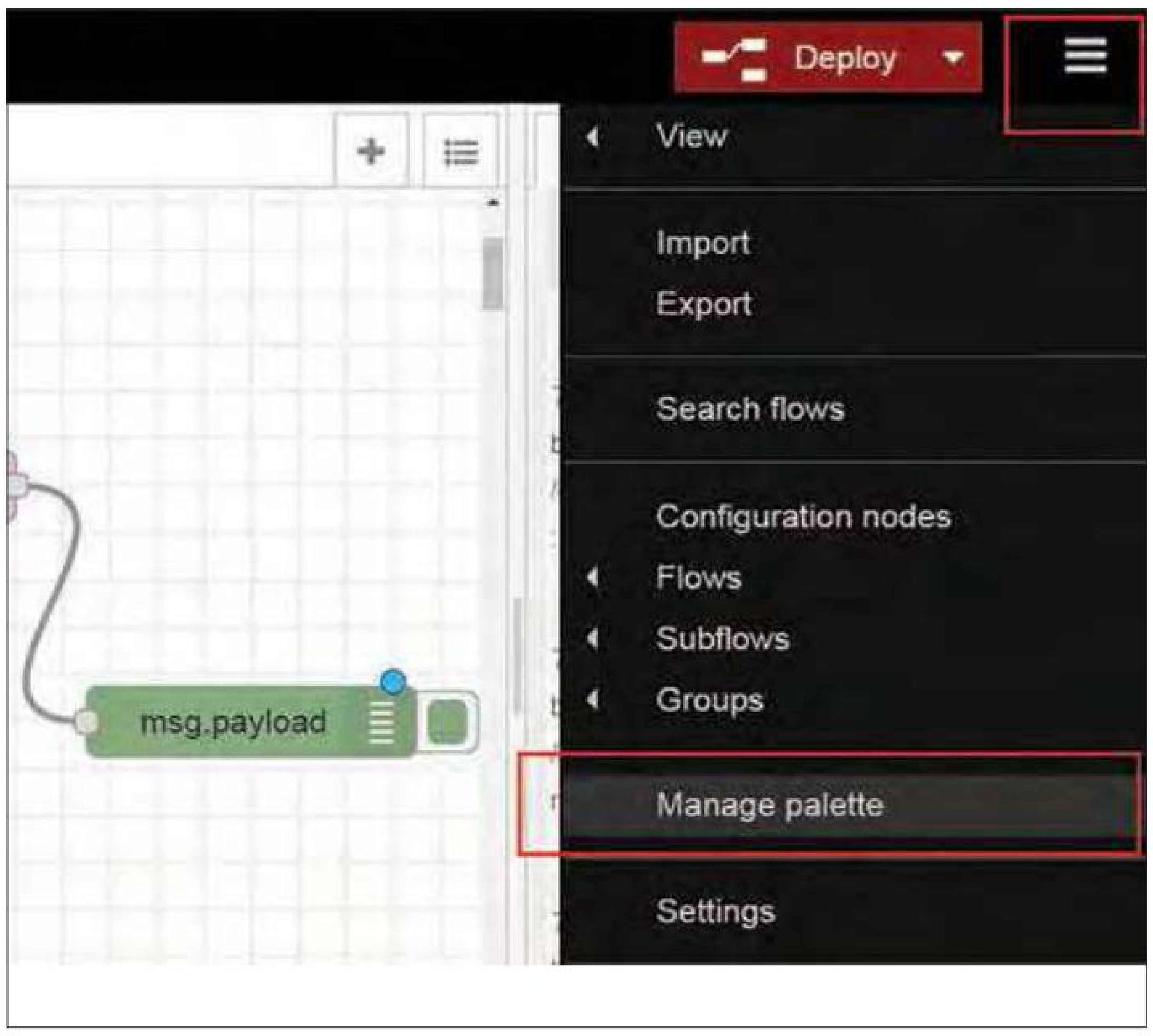


Fig.15. Opening Node-RED Manage palette.

topic in the topic field (eg, `/SERIAL/#` for receiving all messages from Cricket; `/SERIAL/temp` for temperature; and `/SERIAL/batt` for battery voltage). I set the topic to receive all the messages and thus observe all the MQTT data sent by Cricket (see Fig.11).

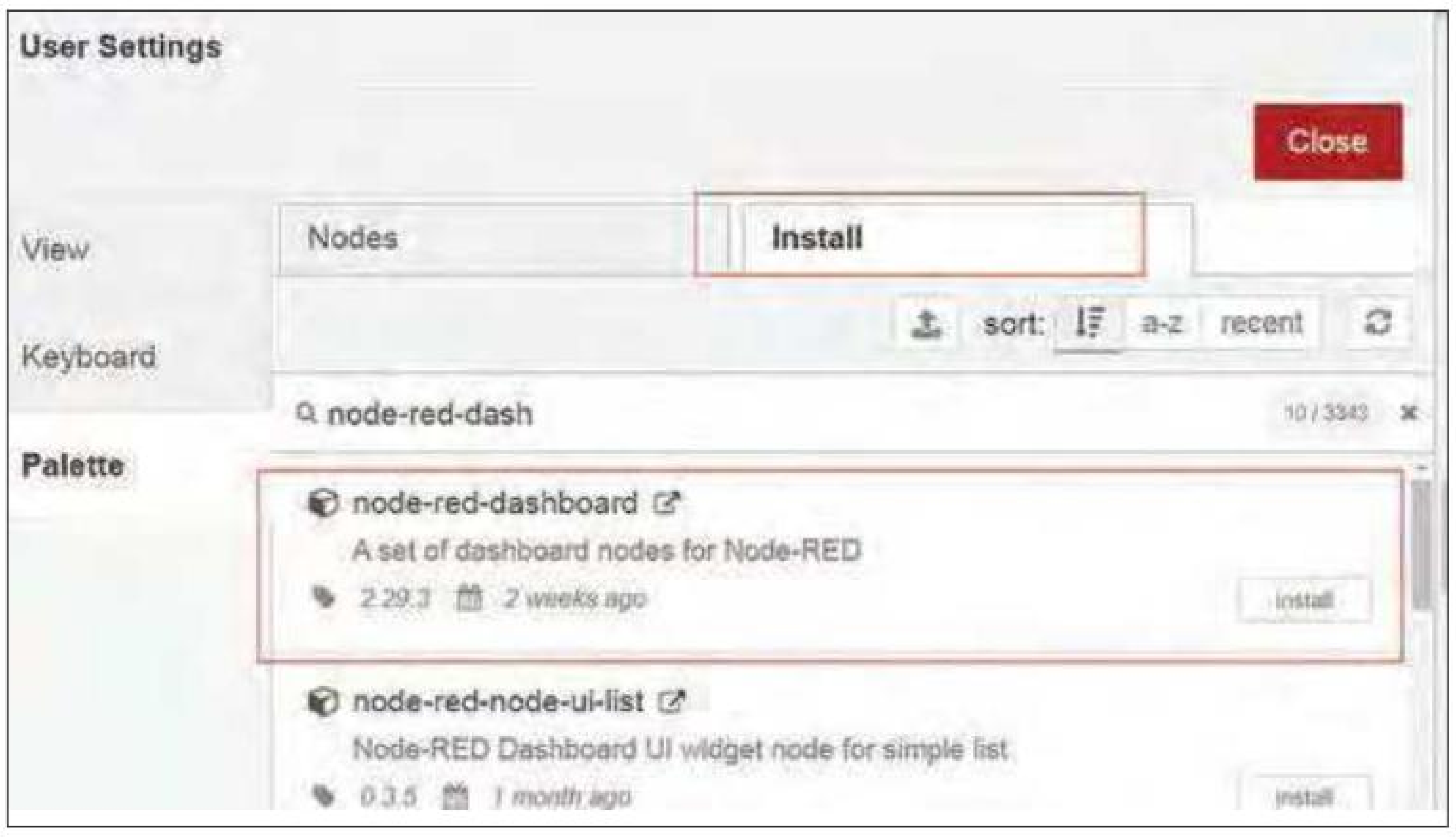
We also need to tell Node-RED to connect to our local MQTT broker from where the messages are expected to be coming. To do this we need to add mqtt-broker by clicking on the pen icon. A new window will open as shown in Fig.12. In the connection tab enter the server name (eg, the IP address of the RPi). Click Add and then Done. See Fig.13.

To watch the received message from the mqtt broker we also need a debug node. Add a debug node and wire it with the mqtt in node. Now deploy the flow and you will receive the MQTT messages from Cricket every 30 seconds, as shown in Fig.14.

Creating a Node-RED dashboard

It would be useful to have a nice user interface (UI) instead of just a raw data print out. The good news is Node-RED enables us to build a good UI, which we will use to build a basic dashboard for our device to plot temperature data and show the battery status.

First, we need to install one extra component called 'node-red-dashboard' for Node-RED. To do that, click on the account icon from top right and select 'Manage palette' – see Fig.15.



node-red-dash

node-red-dashboard
A set of dashboard nodes for Node-RED
2.29.3 2 weeks ago

node-red-node-ui-list
Node-RED Dashboard UI widget node for simple list
0.3.5 1 month ago

Fig.16. Installing node-red-dashboard.

Go to the install tab, type for `node-red-dashboard` and click the install button, as shown in Fig.16. Close the window when done.

Now we are ready to create a dashboard. We already know our device and the topics it is sending out. Therefore, we can precisely set the topics for the data that interest us. In our case, the device is reporting temperature and battery level in the following topics:

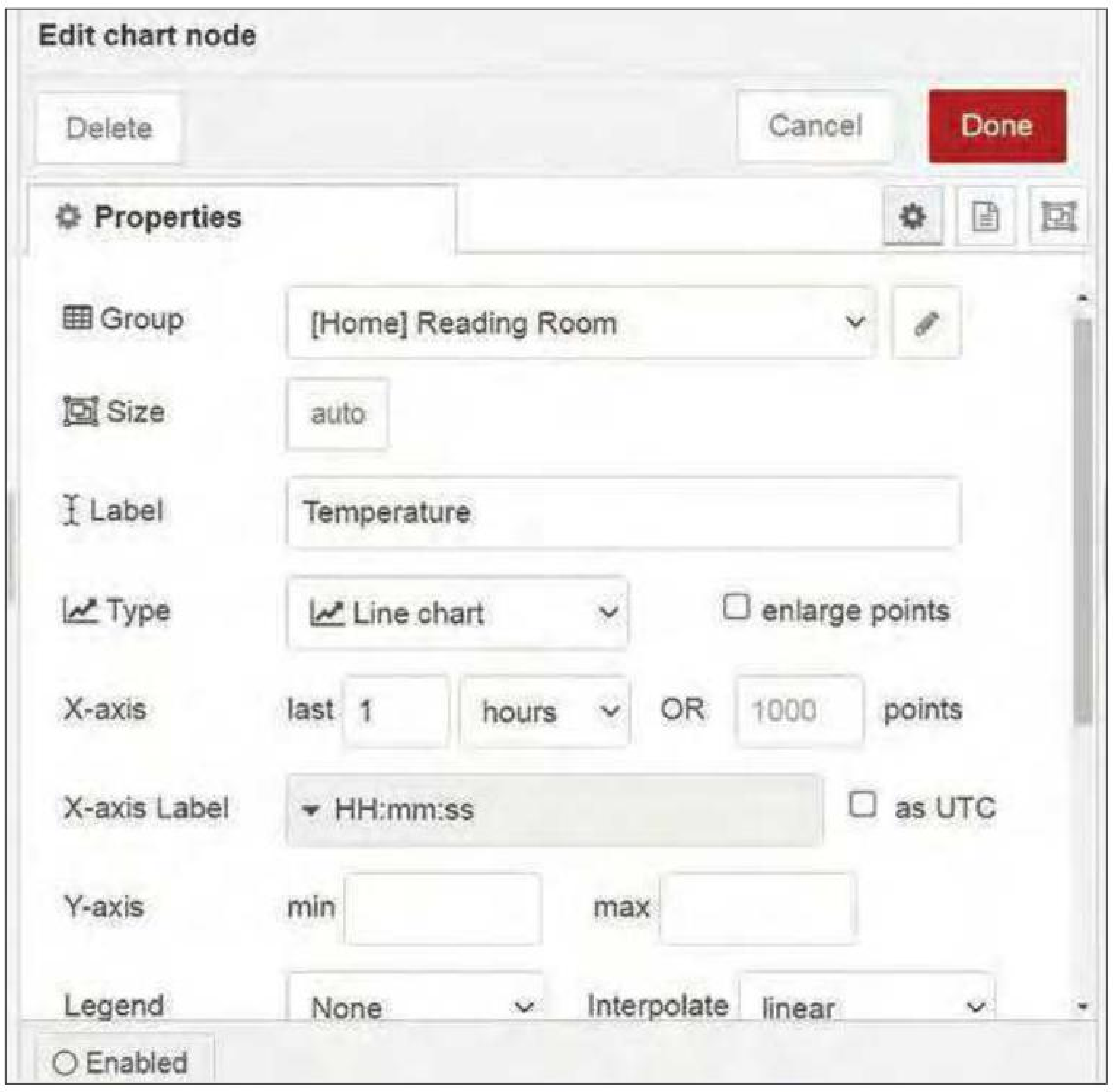
```
/YOUR_CRICKET_SERIAL_NUMBER/temp
/YOUR_CRICKET_SERIAL_NUMBER/batt
```

Therefore, your topic should look something like this:
`/887C3E0039/temp`

Now let's create the whole diagram from scratch. In the workspace, add:

- Two 'mqtt in' nodes and assign the above topics
- A chart node (for temperature) from the dashboard palette and connect it with the temp mqtt input
- A 'gauge' node (for battery) and connect it with the batt mqtt input
- A 'function' node between the batt mqtt input and the gauge node to calculate the percentage power of the battery

You need to assign a group for the chart and gauge nodes. Double click on the nodes and assign 'Home' group with 'Reading Room' Tab for both nodes. Optionally you can set label for the chart and gauge nodes. See Fig.17 for details.



Group: [Home] Reading Room
Size: auto
Label: Temperature
Type: Line chart ☐ enlarge points
X-axis: last 1 hours OR 1000 points
X-axis Label: HH:mm:ss ☐ as UTC
Y-axis: min max
Legend: None Interpolate: linear

Fig.17. Editing chart node.

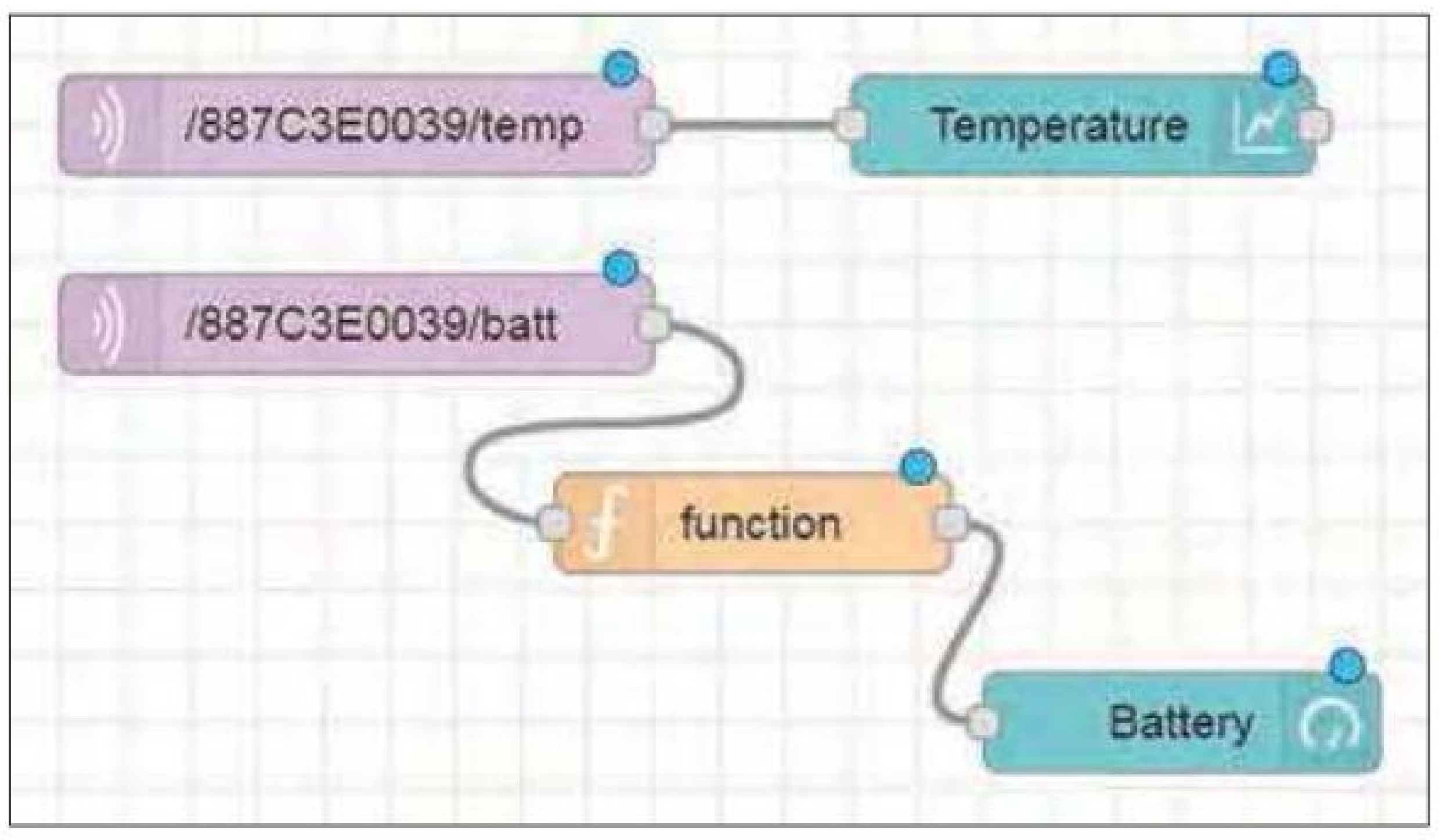


Fig.18. Complete Node-RED flow for receiving sensor data and visualising in graphical dashboard.

Cricket reports a battery voltage with a number from 0-255. We will convert the value to a percentage using the function node. Double click the function node and paste the following lines into the editor and click done:

```
msg.payload = parseInt((msg.
payload / 255) * 100)
return msg;
```

The complete flow will look like Fig.18. Now we are ready to deploy and open our dashboard by using the same link address as we used to open the Node-RED editor. We only need to add a `/ui` suffix at the end of the address. In our case the link looks as follow:

`http://192.168.1.103:1880/ui`

After going to the address, you will find the elegant dashboard shown in Fig.19.

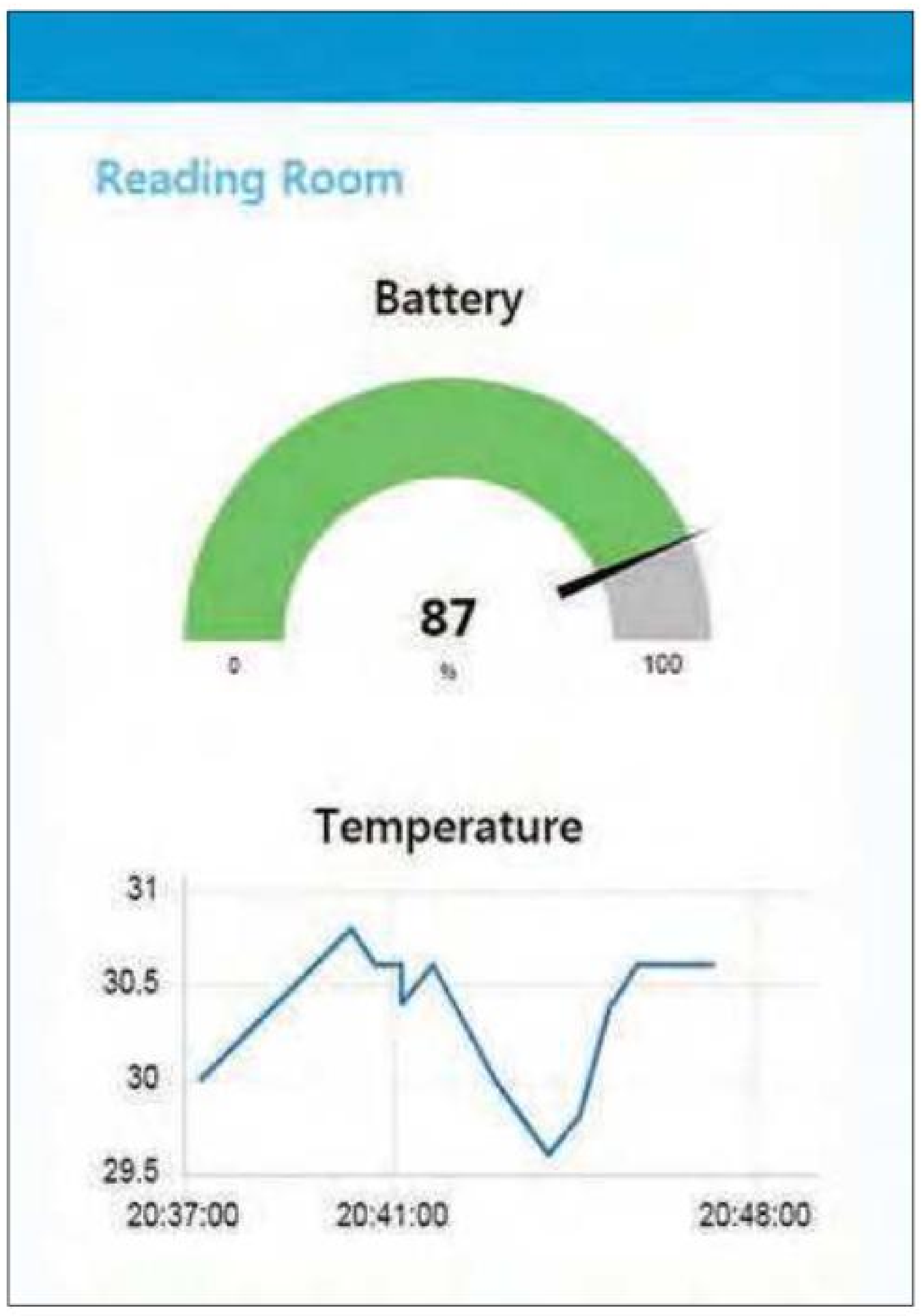


Fig.19. Dashboard created by Node-RED.

Summary

We can now enjoy our own live dashboard of our Wi-Fi automation system on any computer or phone. Of course, this was a very basic project – just putting together a temperature sensor and the basics of creating a simple dashboard. Nevertheless, it's laid the foundations of what we'll need to build on for much more advanced systems in the future.

In this project we have shown the essential hardware and software needed to start building low-power, energy-efficient automation systems. Node-RED and Cricket enable us to build advanced systems without writing any code. This results in a rapid deployment of powerful IoT solutions and automation.

In upcoming articles we will add all sorts of environmental and security sensors and support systems – great things to look forward to!

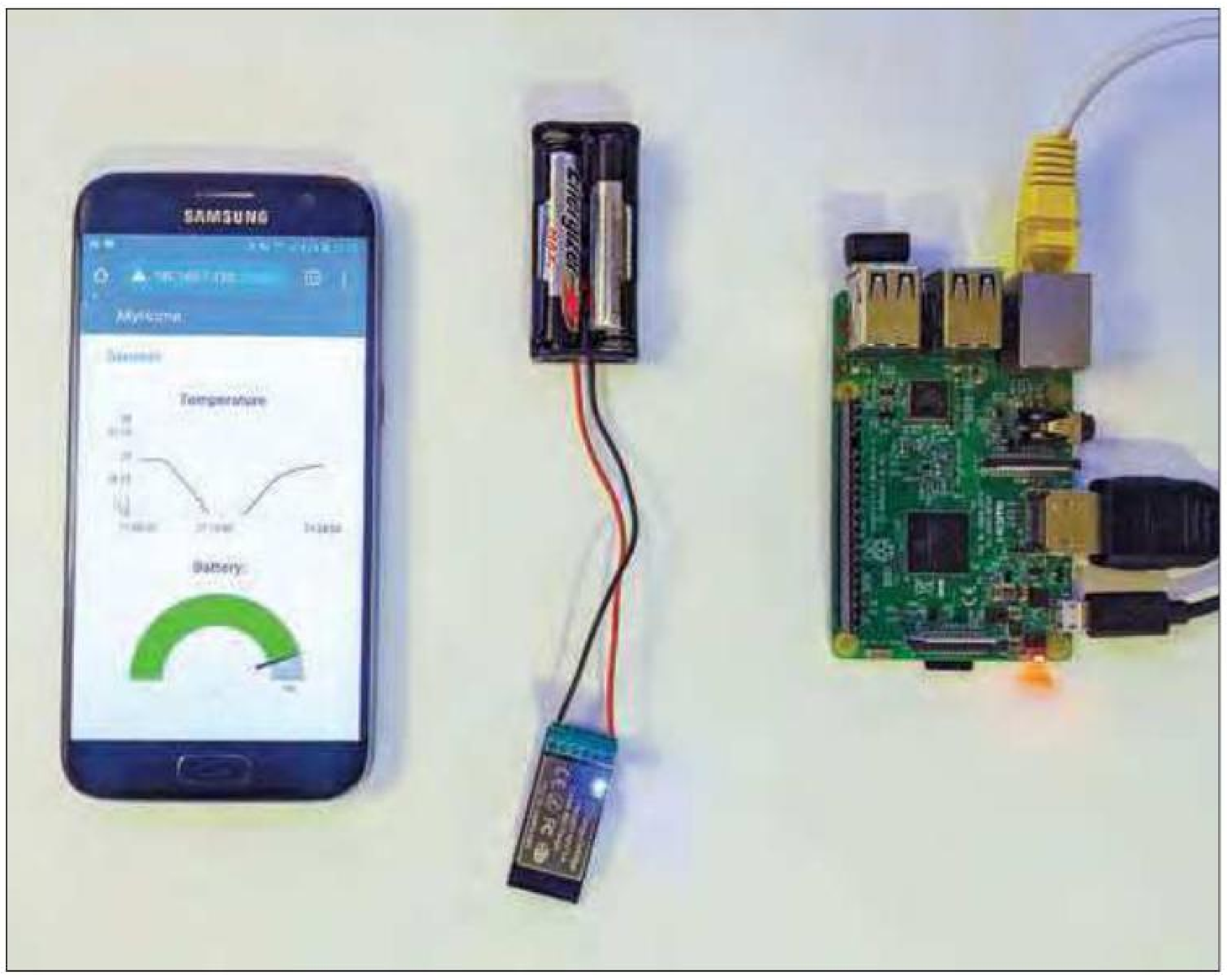


Fig.20. Complete system with Raspberry Pi, live Cricket and the Node-RED dashboard on a smartphone web browser.

Cricket special offer!
PE / OKdo.com

We hope this and June's Cricket articles have inspired you to experiment with IoT and build your own low-cost, low-power Internet of Things projects.

We have agreed a fantastic deal with **OKdo.com** – a unique global seller of SBC and IoT-related components and systems. Until the end of October you can receive a 20% discount on Cricket (while stocks last, limit of two transactions per person), plus free delivery on orders over £25!

To get your Cricket discount, just enter promo code **CRICKETPE** when you check out at the **OKdo.com** online shop:

www.okdo.com/p/things-on-edge-cricket-module

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All of our stock is RoHS compliant and CE approved. Visit our well stocked shop for all of your requirements or order on-line.

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KickStart

by Mike Tooley

Part 5: Getting to grips with EMC

Our occasional *KickStart* series aims to show readers how to use readily available low-cost components and devices to solve a wide range of common problems in the shortest possible time. Each of the examples and projects can be completed in no more than a couple of hours using 'off-the-shelf' parts. As well as briefly explaining the underlying principles and technology used, the series will provide you with a variety of representative solutions and examples, along with just enough information to be able to adapt and extend them for your own use.

This fifth *KickStart* instalment explains the importance of electromagnetic compatibility (EMC) with some practical hints on how to reduce electromagnetic interference (EMI) and electromagnetic susceptibility (EMS) in your PCBs, circuits and projects.

Those of you that are as old as me will doubtless recall the seemingly endless 'smog' that we had to live with in the 1950s. 'Smoke fog' was an unpleasant consequence of the UK's increasing post-war reliance on coal as a fuel, leading eventually to the introduction of the United Kingdom Clean Air Act in 1956. Less visible, but still undesirable, is the 'electronic smog' that surrounds the growing number of electronic devices that we rely on in our everyday lives. And, while you might be blissfully unaware of 'electronic smog', it can still have a serious impact on the environment in which it is placed. Consequently, electromagnetic compatibility (EMC) has become an important consideration in the design and use of any item of electronic or electrical equipment – but, before delving deeper into this important and often misunderstood subject, it's perhaps worth exploring what we mean by 'electromagnetic compatibility' and how it relates to the two associated terms 'electromagnetic interference' (EMI) and 'electromagnetic susceptibility' (EMS).

Put simply, EMS is a measure of how a device reacts to the electromagnetic environment in which it is used, while EMI is an indicator of how much a device impacts its electromagnetic environment. Thus, EMI and EMS are both important when considering an equipment's compatibility with the environment in which it is used.

Why is all this significant? Simply this, when designing, constructing and using electronic equipment we need to consider how the equipment will interact with the electromagnetic environment in which it is placed. Furthermore, failure to observe EMC precautions can have serious consequences. In the commercial world and in most, but not all countries, emissions that cause potential interference to other apparatus and services are strictly regulated. It is also worth noting that EMC regulations normally specify limits on acceptable levels of interference, and often specify tests to be carried out to verify compliance.

Sources of EMI

Electromagnetic emissions can (and do) arise from various sources within any item of electronic equipment. Emissions may be *radiated* in the form of electromagnetic (radio) waves, or they may be *conducted* from the equipment along power lines and other wiring. In most countries, limits on the magnitude of these emissions are imposed by regulatory bodies. These limits are designed to protect all users of the radio spectrum from the effects of harmful or annoying interference which may degrade the performance of other nearby electronic equipment. Common EMI sources include:

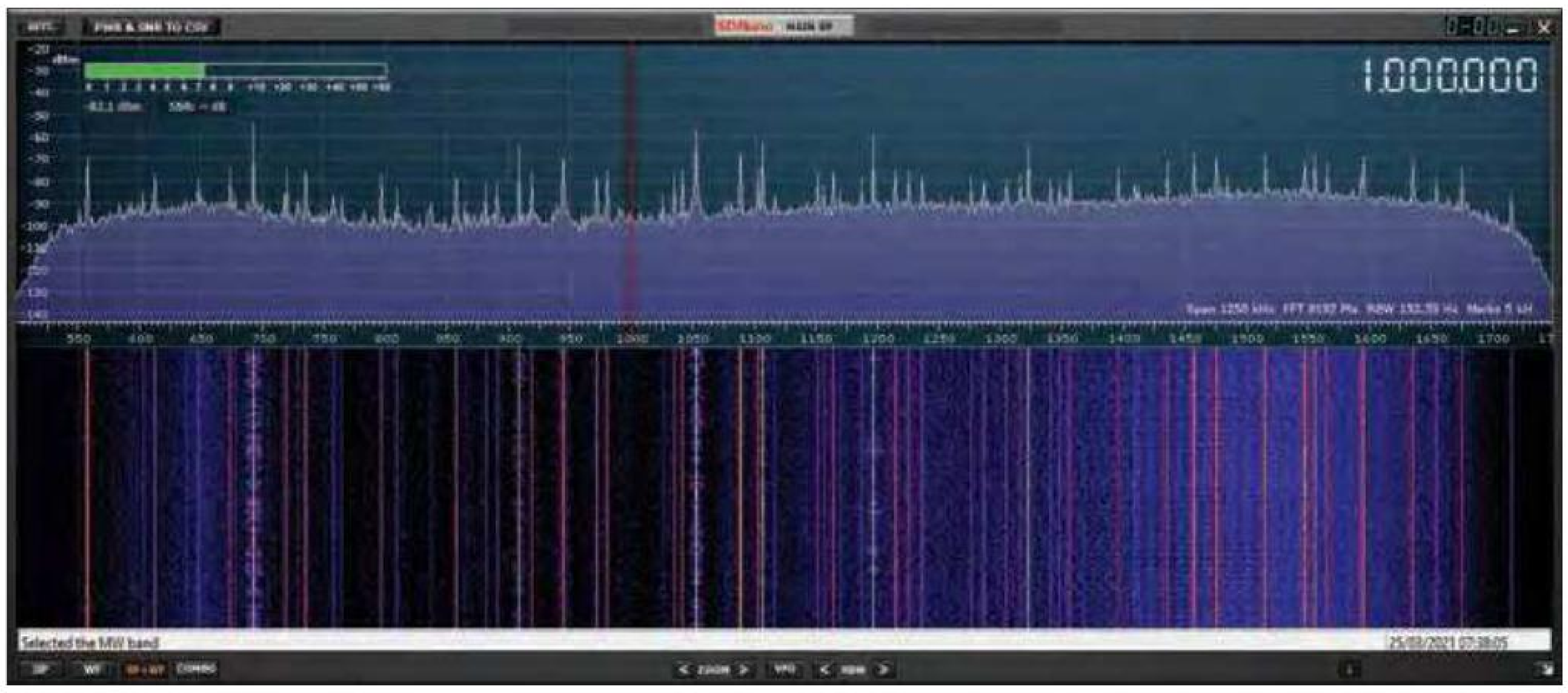

Fig.5.1. Spectral analysis of the MW band in the author's workshop.

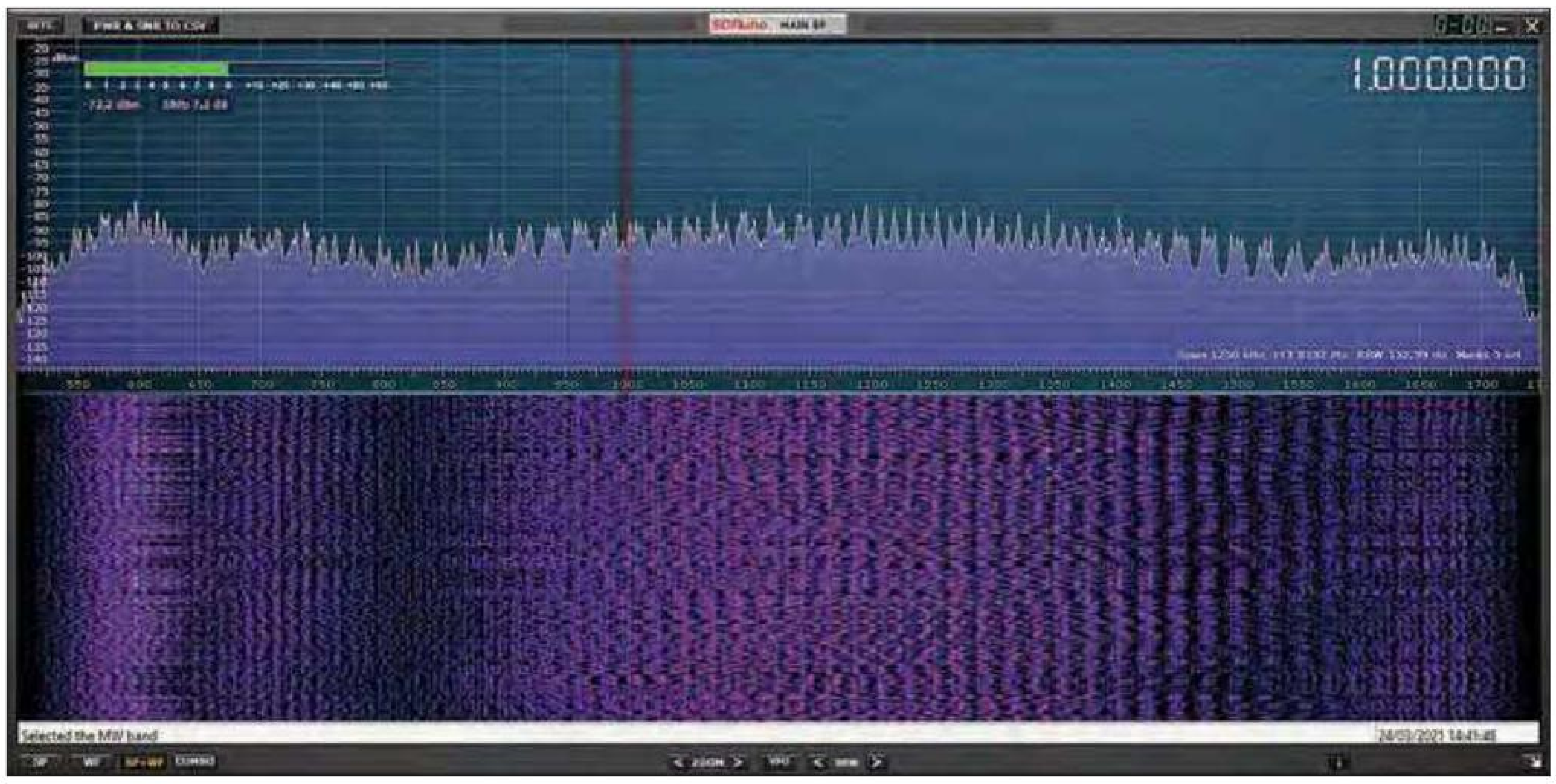

Fig.5.2. Spectral analysis repeated in the vicinity of an EMI-producing SMPS.

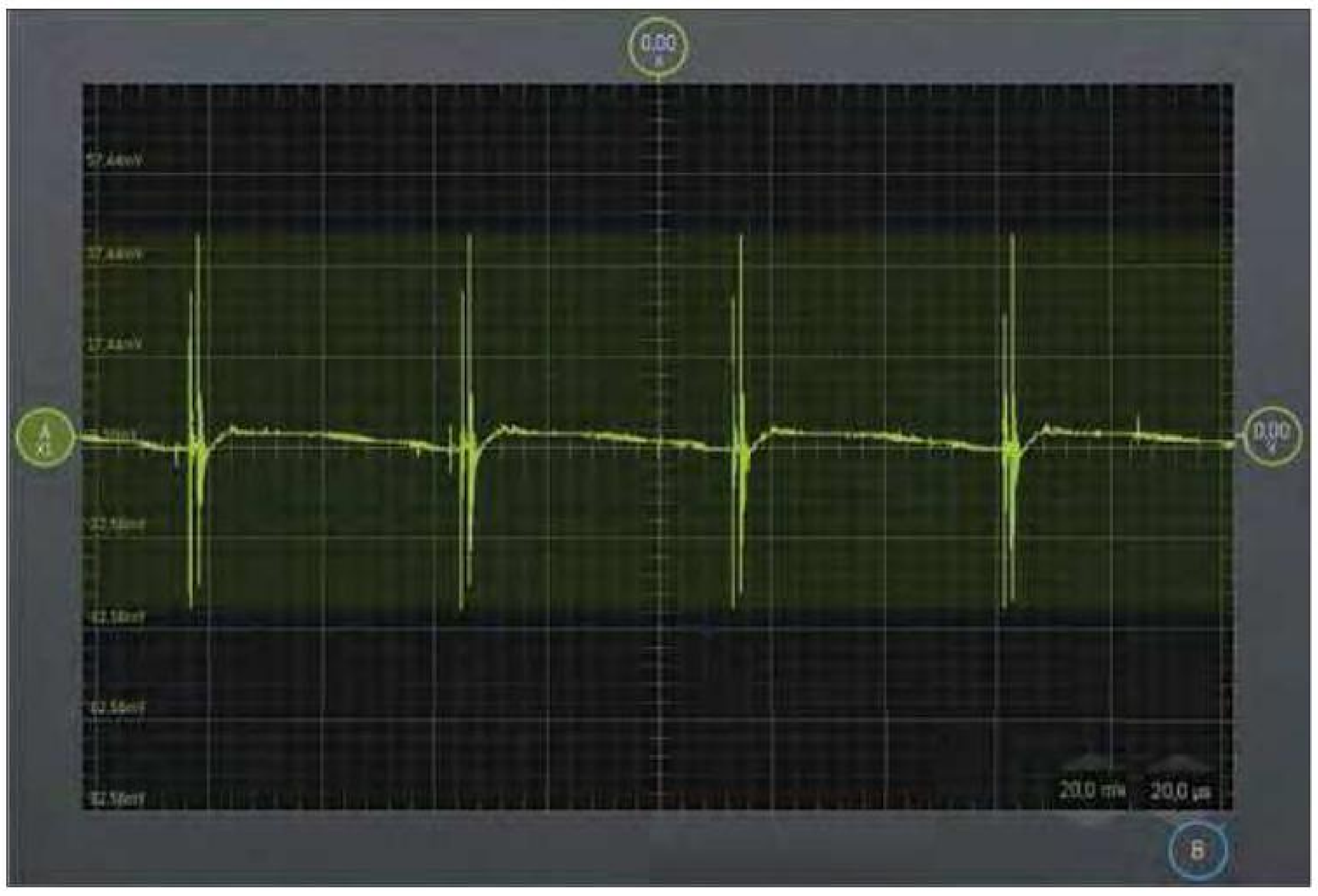

Fig.5.3. Waveform of the output of the EMI-producing SMPS.

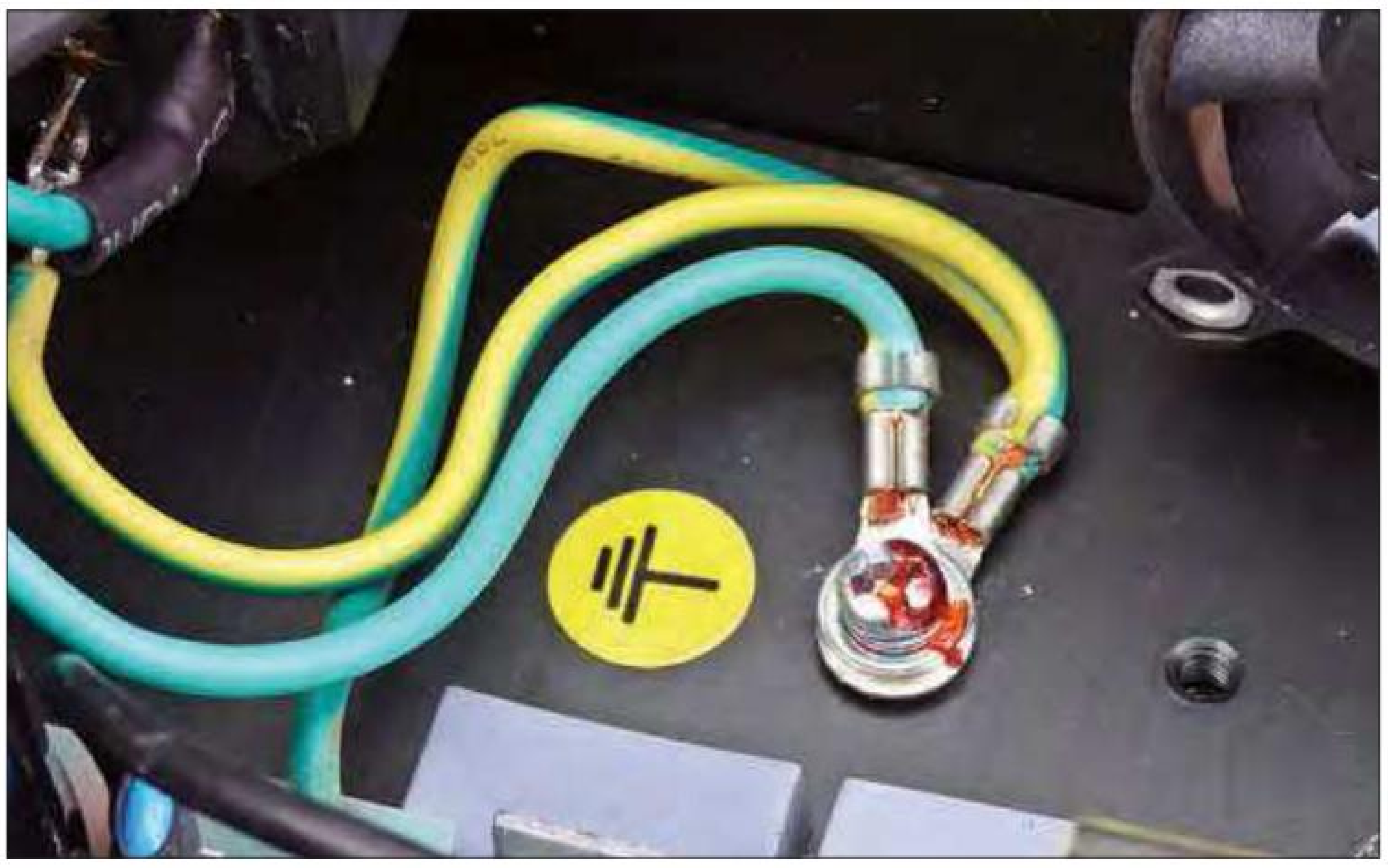

Fig.5.4. Effective grounding to a metal enclosure can be important to comply with EMC regulations.

- Active (radiating) antennas and their associated feeders when poorly matched or inadequately screened
- Fundamental and harmonic components of repetitive waveforms such as clock signals or switching waveforms used in an SMPS (switched-mode power supply)
- Unwanted 'parasitic' oscillation resulting from poor circuit design and/or layout
- Transients caused by short-duration pulses
- Radiation of wideband noise from magnetic components.

To put this into a practical context, Fig.5.1 shows the normal frequency spectrum and waterfall display of radio signals in the medium wave (MW) band in the author's workshop. The spectrum display shows signal amplitude over the range extending from 500kHz to 1.8MHz, while the waterfall shows how signal amplitude varies with time. Individual broadcast MW signals can be clearly seen, and the noise floor is at around –100dB. Compare this spectrum with that shown in Fig.5.2 when a low-cost 5V switched-mode power supply (SMPS) is operated in the vicinity of the spectrum analyser's antenna. Note how the noise floor has risen by about 18dB with broadband spurious harmonic components masking all but the strongest broadcast signals.

The waveform at the output of the EMI-producing 5V SMPS is shown in Fig.5.3. This reveals a switching transient with an amplitude of 100mV and a repetition frequency of around 20kHz (the power supply's switching frequency). Additional filtering and screening are urgently needed to improve performance and comply with the relevant EMC regulations!

A quick check procedure

Accurate methods of investigating EMI involve the use of specialist test equipment (spectrum analysers, test fixtures and calibrated antennas) that is usually only available in test labs (see *Going further* at the end). Despite this, a quick check on the level of EMI produced by a suspect item of electronic equipment (such as an SMPS) can be carried out using nothing more than a portable MW AM radio receiver. Placing the receiver close to the equipment under investigation and sweeping it across the MW band (around 1MHz) will usually reveal some radiated noise. Then, moving it away from the equipment following the connecting cables and supply leads should reveal the presence of any conducted noise. Using this technique, it is possible to obtain a quick assessment of the performance of EMI improvement methods, such as screening, grounding and filtering.

Improving EMC performance

There are various ways of improving EMC performance to reduce the amount of EMI produced by a 'noisy' item of electronic equipment. Measures can also be taken to prevent the ingress of noise to reduce susceptibility to EMI experienced by nearby equipment.

1. Shielding and grounding

EMC performance is significantly improved by effective shielding (screening) and grounding (earthing). Not only can this help to reduce radiation from noise-producing circuitry, but it will also help reduce the ingress of noise experienced by equipment that might be suffering the effects of EMI. An effective low impedance path to ground is an essential pre-requisite. This helps bypass noise currents to ground (zero potential) thereby reducing the noise potential that might exist between a component's 0V pin and the supply ground. To eliminate unwanted ground loops a single common ground point is often used for internal wiring (see Fig.5.4). This helps to avoid the situation in which small noise voltages enter the signal path between multiple ground points.

Screening is important to prevent unwanted signals from being radiated from equipment. Screening should be a continuous grounded metal surface. This is often aluminium, steel or tinplate of an appropriate gauge which must be grounded at several points. It's important to ensure that adequate ventilation is included in the screening design – equipment that produces heat should *not* be totally enclosed for obvious reasons! Wire mesh and/or small ventilation holes are usually permissible unless the frequencies concerned are high, in which case primary internal as well as secondary outer screening is needed.

2. PCB considerations

The PCB design can be crucial in optimising EMC performance, and it is essential that the design process takes this into consideration. Stages in an EMC-compliant design process might involve the following:

- Physical parameters such as size, shape and the number and function of PCB layers
- Selection and placement of individual components and off-board connectors
- Track layout and routing (including power supply rails)
- Grounding of common 0V tracks and decoupling of power rails
- Shielding of signal leads and interconnecting wiring.

Critical areas of the circuit need to be identified to ensure that that circuitry is kept within functional groups. For example, a pre-amplifier should be positioned well away from a power supply, a sensitive detector away from a switching converter, and so on. Similarly, components that are likely to carry appreciable currents need to be positioned close to the rails or grounds that connect them. PCB tracks should be kept as wide as possible to minimise

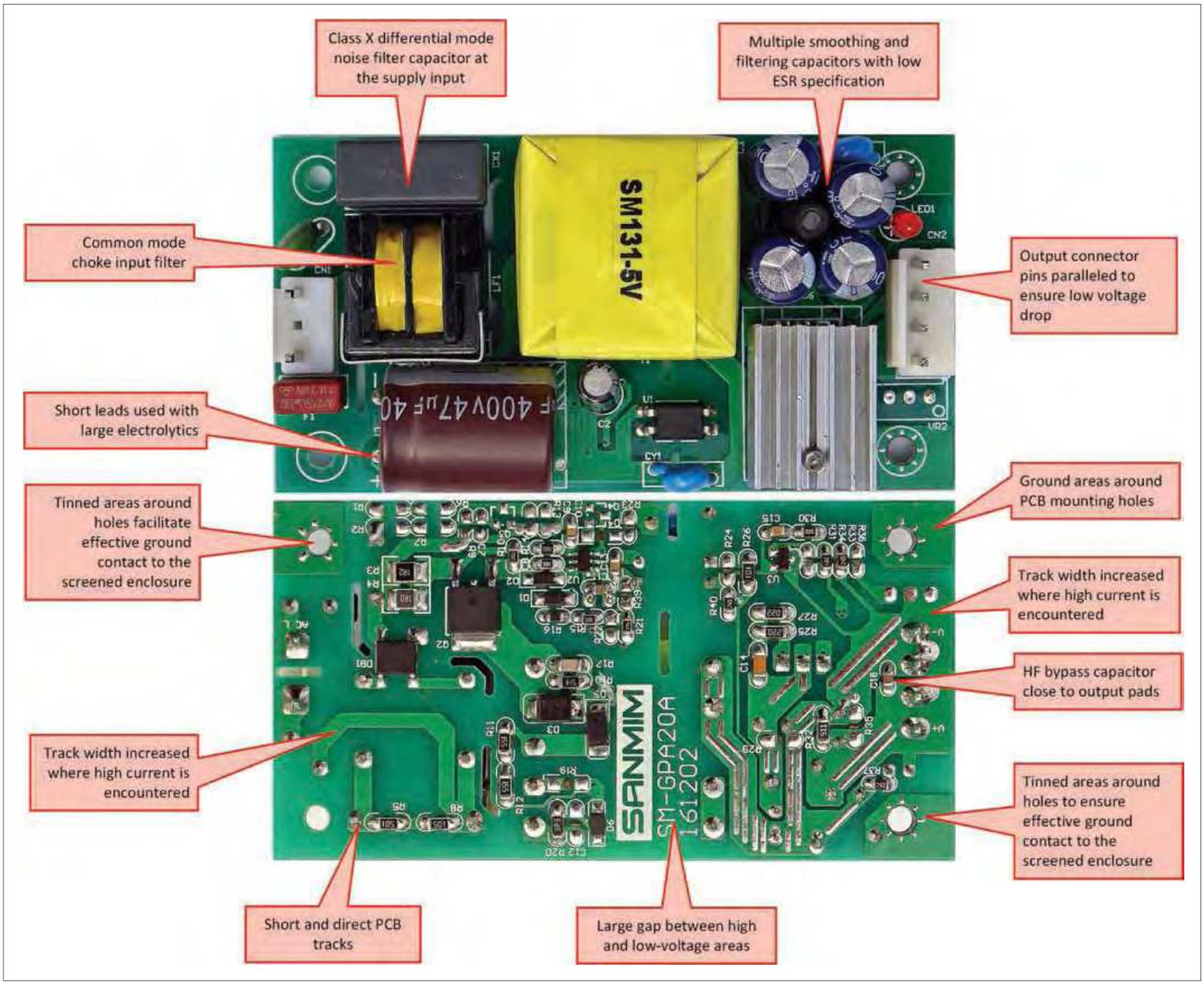
Class X differential mode noise filter capacitor at the supply input
Multiple smoothing and filtering capacitors with low ESR specification
Common mode choke input filter
Output connector pins paralleled to ensure low voltage drop
Short leads used with large electrolytics
Tinned areas around holes facilitate effective ground contact to the screened enclosure
Ground areas around PCB mounting holes
Track width increased where high current is encountered
HF bypass capacitor close to output pads
Track width increased where high current is encountered
Tinned areas around holes to ensure effective ground contact to the screened enclosure
Short and direct PCB tracks
Large gap between high and low-voltage areas
SM131-5V
SANMIM
SM-GPA20A
161202

Fig.5.5. An example of EMC design considerations for good EMC performance.

voltage drops and dedicated copper 'land' used to extend the ground area around HF (high-frequency) and RF (radio-frequency) circuits – see Fig.5.5.

EMC-compliant PCB design techniques are gained with experience, but in the meantime it's well worth examining any boards that you have to hand in order to gain an insight into professional layout techniques.

Sensitive analogue circuitry should always be kept apart from digital circuitry (where rapidly changing logic levels of several volts may be present). Not only should analogue and digital circuitry be physically separate, but also, they should be electrically separate and the key to this is the use of entirely separate supplies with separate decoupling and ground points.

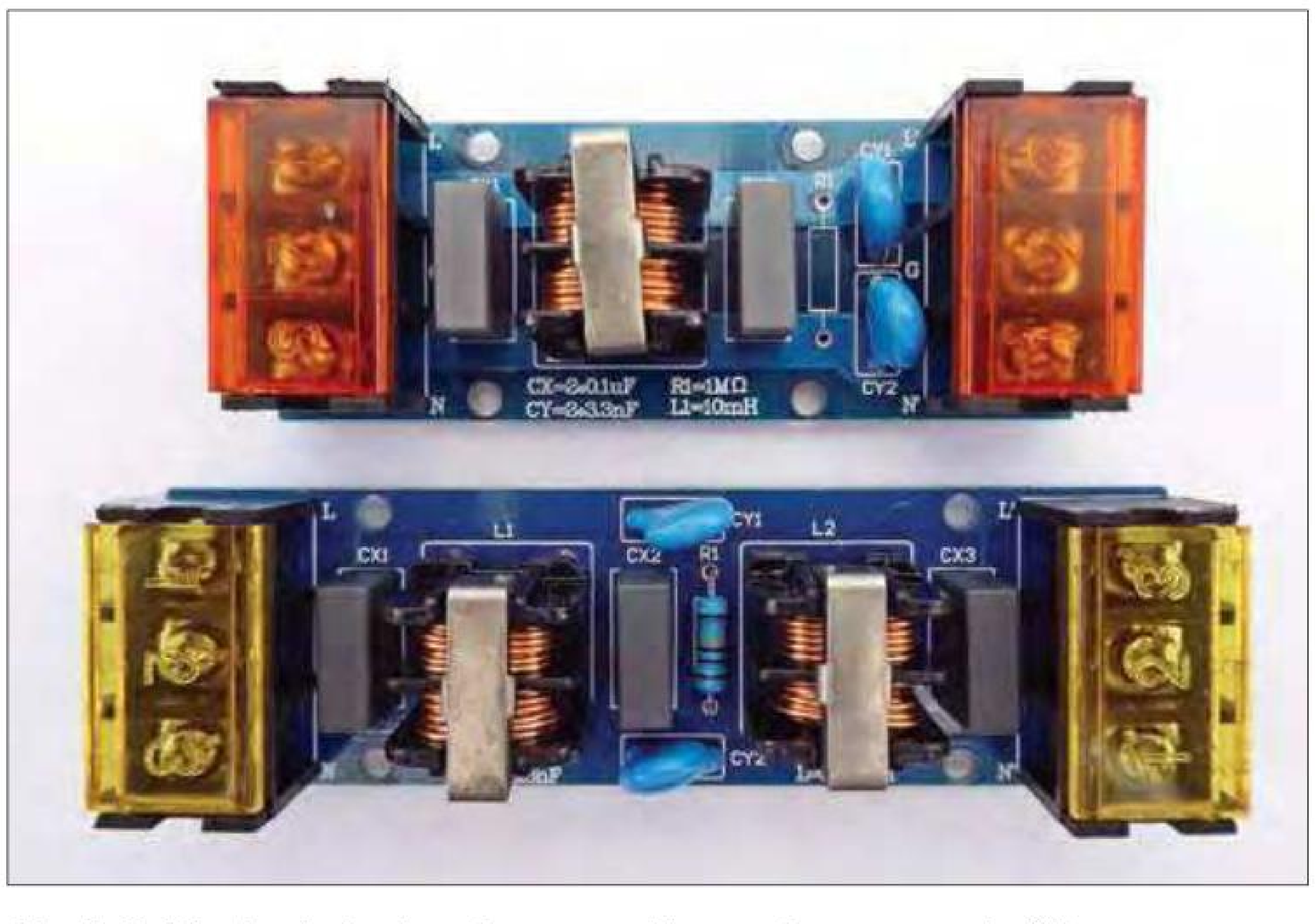

Fig.5.6. Typical single-stage and two-stage supply filters.

Crosstalk can occur between adjacent signal lines or PCB tracks. The amount of crosstalk depends on the shared reactance – capacitive or inductive – between the two signal paths. Capacitively induced crosstalk occurs when mutual capacitance links two signal paths whereas inductively induced crosstalk occurs when adjacent signal paths are linked by mutual inductance (a similar effect to a pair of coupled windings on a transformer). Note that, in many cases, both effects may be present at the same time. The effects of crosstalk can be minimised by reducing the coupling (capacitive or inductive) between the conductors.

Transmission lines and bus lines should always be matched or terminated with their specified characteristic impedance.

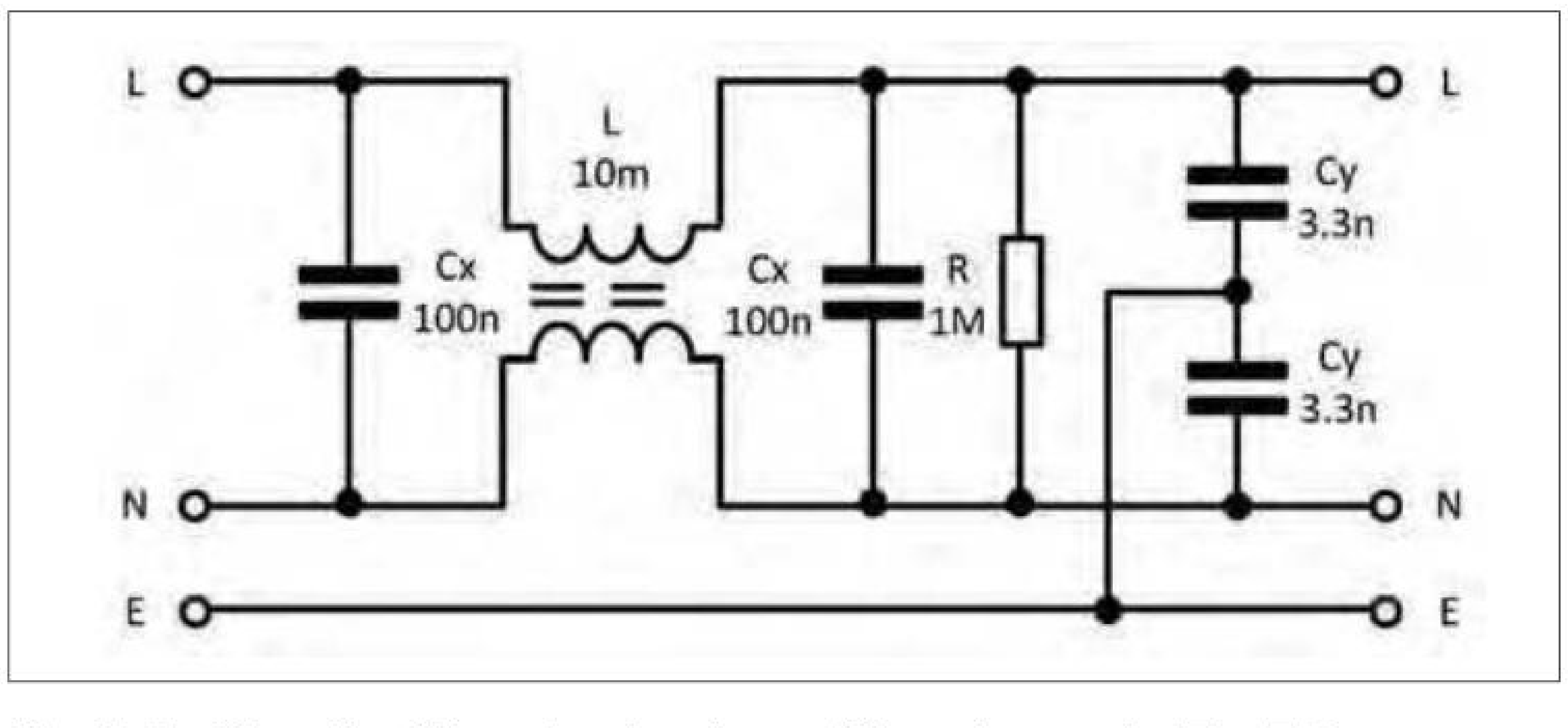
L
L
10m
Cx
100n
Cx
100n
R
1M
Cy
3.3n
Cy
3.3n
L
N
N
E
E

Fig.5.7. Circuit of the single-stage filter shown in Fig.5.6.

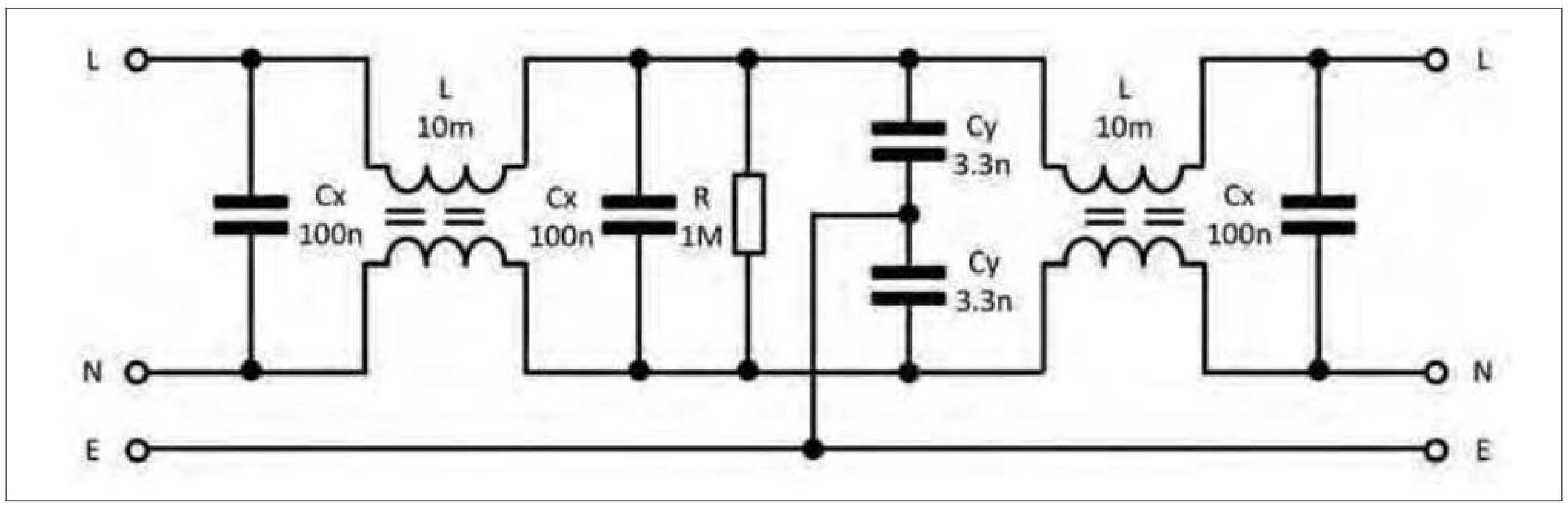

Fig.5.8. Circuit of the two-stage supply filter shown in Fig.5.6.

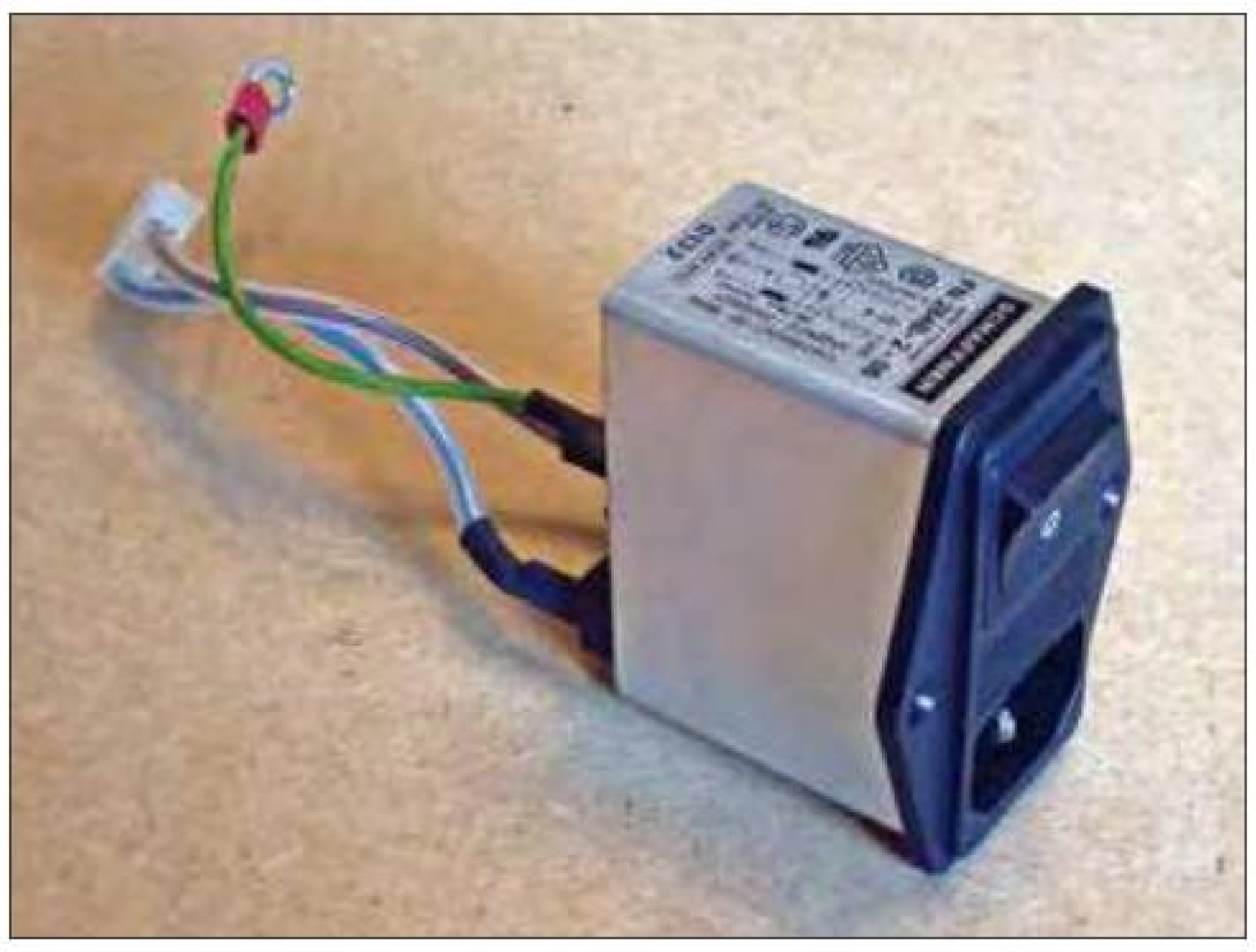

Fig.5.9. An EMI filter fitted in an IEC mains connector.

This helps to reduce the presence of standing waves and 'ringing'. A substantial ground or 'land' area may also be required for VHF and UHF PCB applications. 'Guard' areas where high-impedance signal tracks and pins are surrounded by grounded copper track may also be required to minimise capacitive coupling and protect high-impedance points.

3. Supply filters

Supply filters are usually fitted at or close to power connectors and in some cases, filters can also be present within I/O connectors (Ethernet connectors often incorporate common-mode filters). Fig.5.6 shows two commercial pi-section supply filters. The smaller filter comprises a single inductor with two Class-X and two Class-Y capacitors, as shown in Fig.5.7. The larger filter has two cascaded stages with two inductors, three Class-X and two Class-Y capacitors.

This filter also incorporates a 1MΩ discharge resistor, R1 (not present in the smaller single-stage filter). Note that, in both cases the two inductor windings are wound in opposite directions and so they tend to cancel the common-mode currents.

The two filters shown in Fig.5.7 combine two different network topologies. The Class-X capacitors are designed to filter differential-mode currents, while the common-mode inductor and Class-Y capacitors are designed to filter common-mode noise. The resistor shown is usually 100kΩ to 200kΩ and its purpose is to provide a discharge path for any residual line voltage stored on the capacitors.

Measurements carried out by the author reveal that the single-stage filter has a rejection of greater than 30dB at 1MHz while the two-stage filter provides a rejection in excess of 60dB at the same frequency. Fig.5.9 shows an EMI filter fitted inside an IEC mains

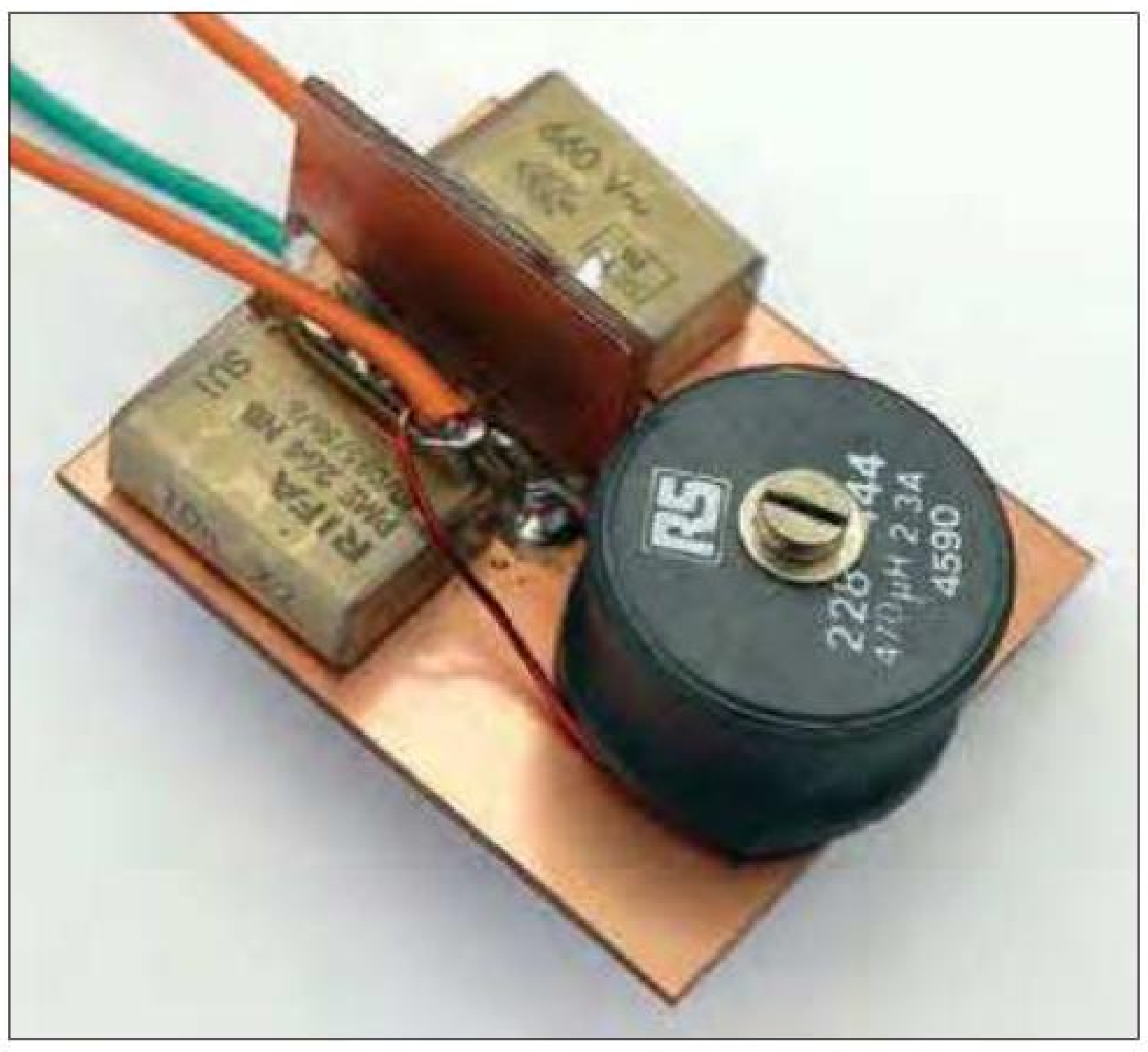

Fig.5.10. A simple home-constructed pi-section filter offering a rejection of 40dB at 1MHz.

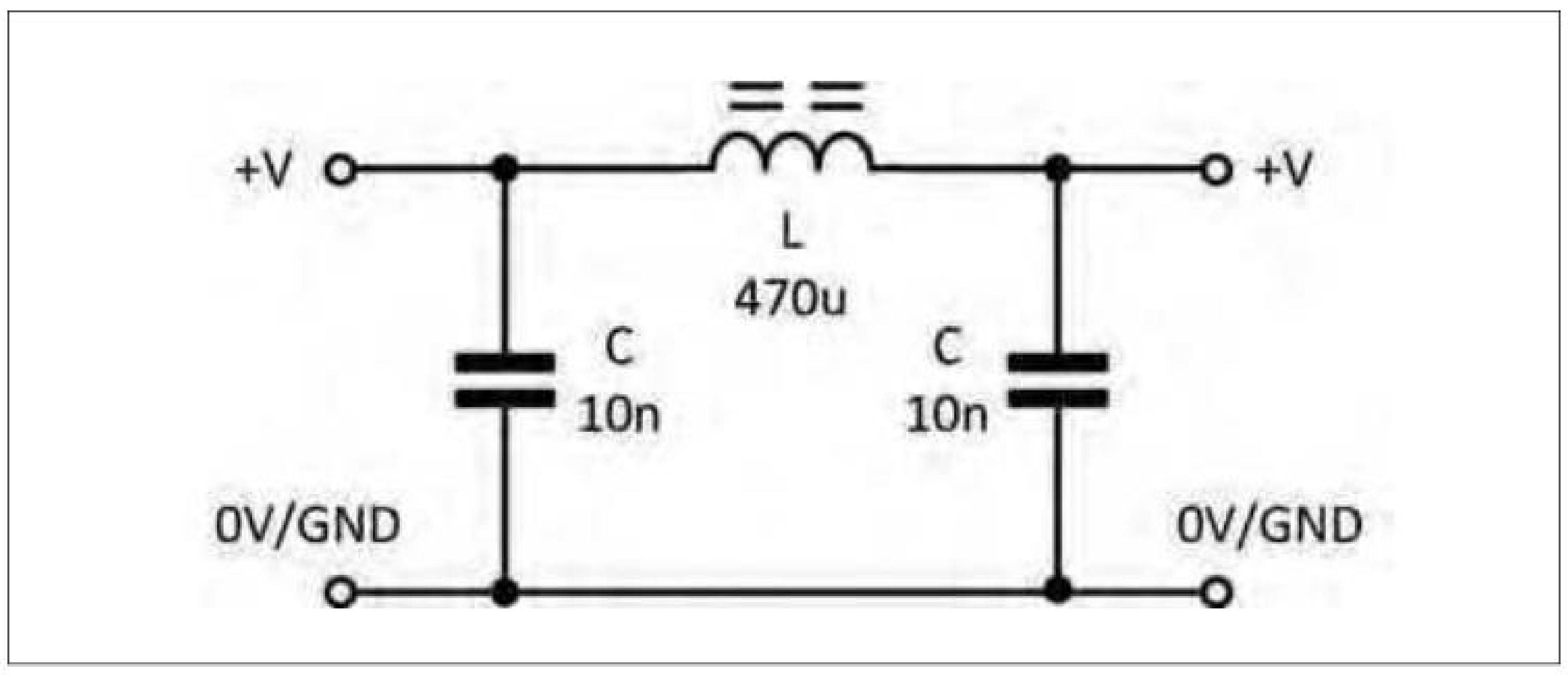

Fig.5.11. Circuit of the home-constructed filter shown in Fig.5.10.

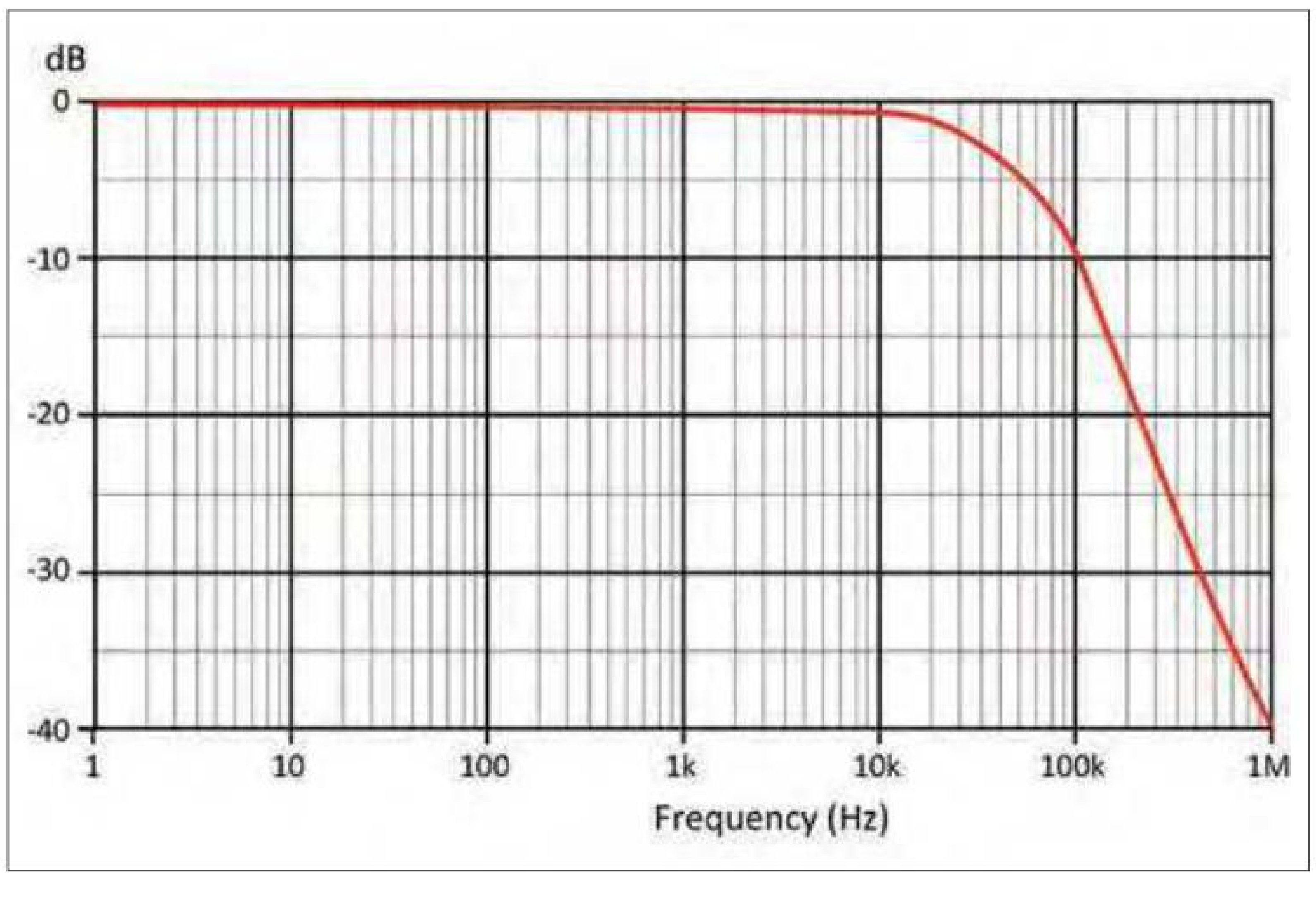

Fig.5.12. Frequency response of the home-constructed filter shown in Fig.5.10.

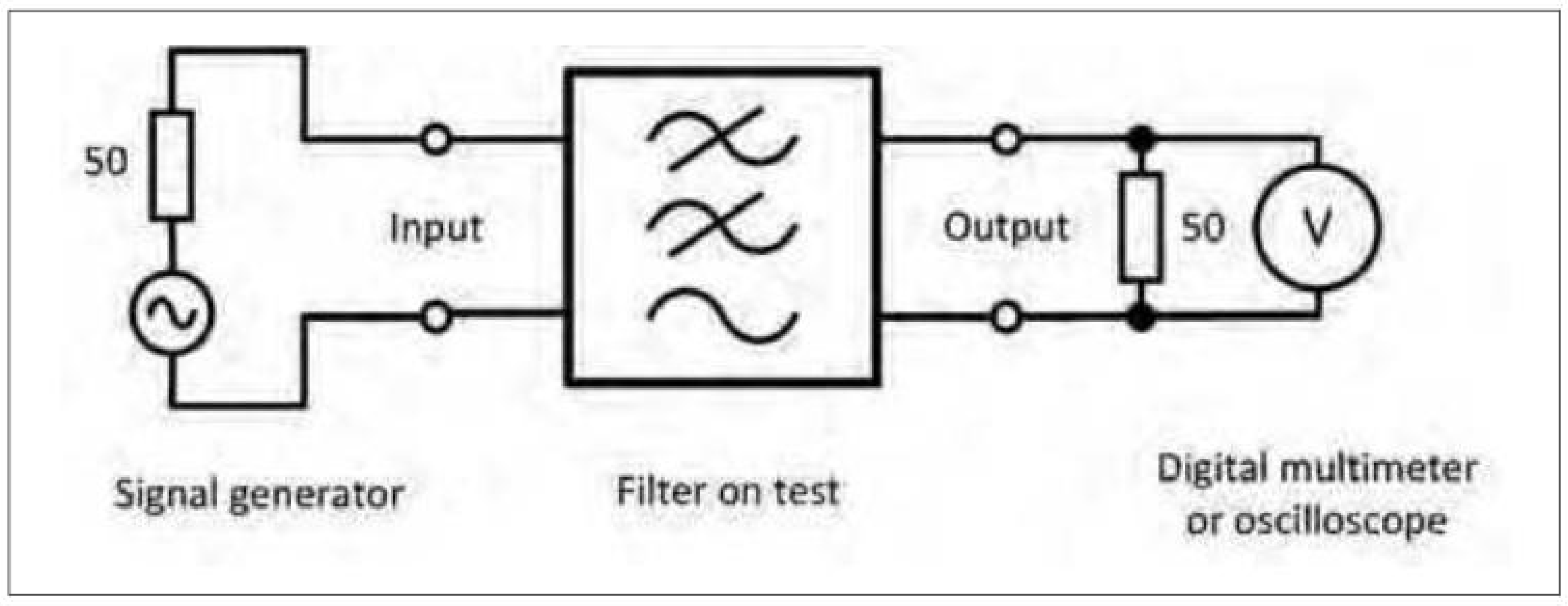

Fig.5.13. Test circuit used to obtain the characteristic shown in Fig.5.12.

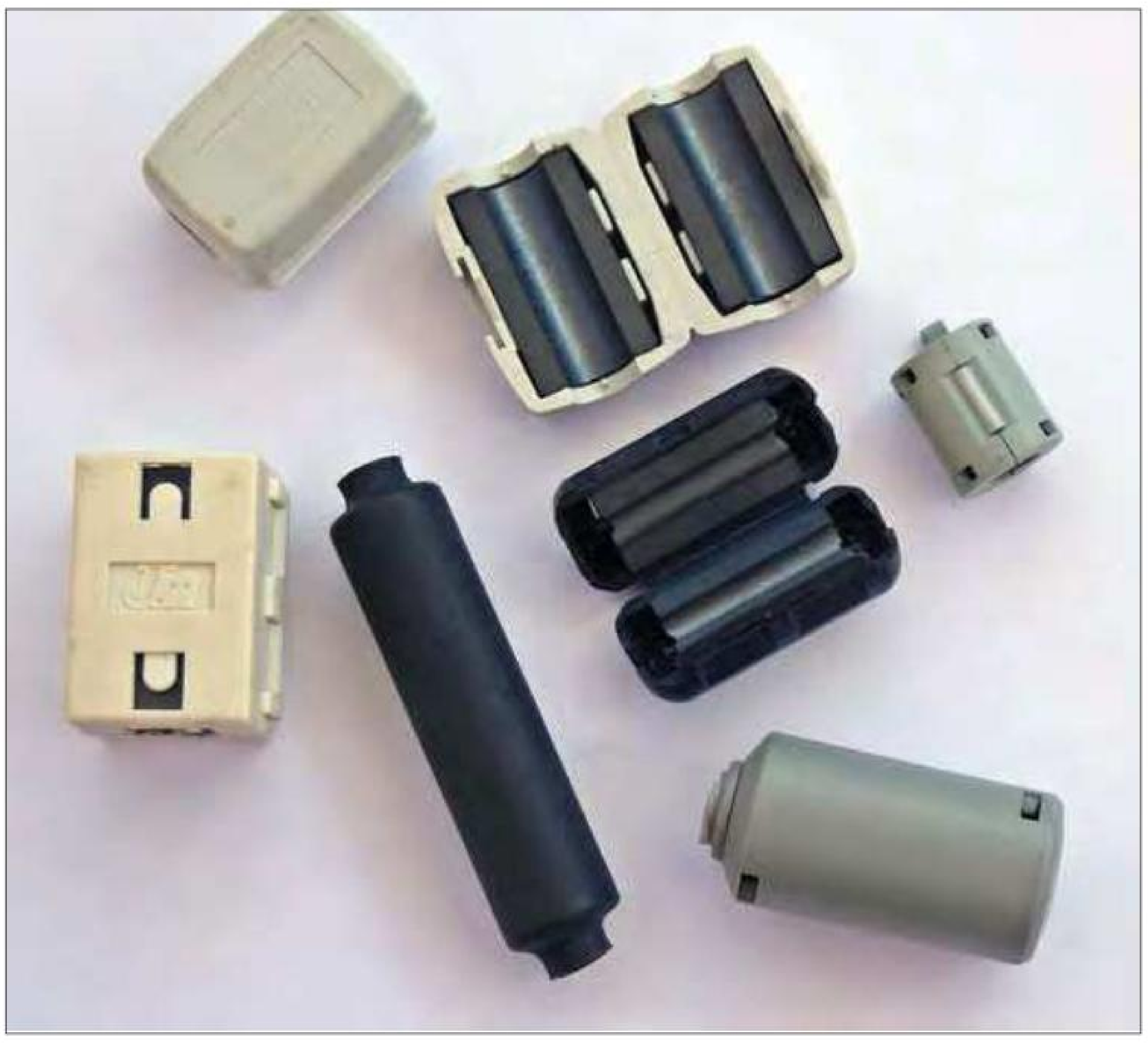

Fig.5.14. Ferrite core filters suitable for clamping onto cables.

Table 5.1: Going Further with EMC

Topic	Source	Notes
EMC regulations and directives	The UK Electromagnetic Compatibility Regulations 2016 can be found at: **https://bit.ly/pe-oct21-ks1** The EU Electromagnetic Compatibility (EMC) Directive can be found at: **https://bit.ly/pe-oct21-ks2**	
YouTube videos	The Slovenian Institute of Quality and Metrology (SIQ) provides a short introduction to EMC at: **https://youtu.be/8SbegmFJ_WM** Power Electronics Basics provides a detailed discussion of EMC and EMI at: **https://youtu.be/C2UDpUAgoSQ** Andy Lawson's Beginner's Guide to EMC can be found at: **https://youtu.be/n4tB2UqZN6c**	The short SIQ video also provides a glimpse into a modern EMC testing laboratory. By contrast, Andy Lawson's comprehensive lecture lasts nearly an hour.
Filters	*Part 8* of *Electronics Teach-in 4* (available from *PE* magazine) provides a general introduction to analogue circuit applications including passive and active filters.	The Coilcraft website (see below) provides some useful information in the form of application notes on the design of L-C filters.
Ferrite cores	The Laird Technology website has a useful guide to ferrite EMI cable cores: **https://bit.ly/pe-oct21-ks3** The Coilcraft website provides a useful introduction to inductors and chokes at: **https://bit.ly/pe-oct2-ks4** A similar guide is available from TDK at: **https://bit.ly/pe-oct21-ks5**	The Laird guide a useful "rule of thumb" guide to selecting ferrite cores for use in EMI suppression. The TDK guide shows test equipment set-up used for measuring the performance of ferrite clamp-on filters. A wide range of clamp-on ferrite cores is available from Mouser Electronics: **www.mouser.co.uk**

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connector. Note that the filter is completely enclosed in an aluminium case which must be properly earthed to ensure satisfactory performance (see earlier).

A simple home-constructed pi-section filter for a low-voltage DC supply (up to 50V at 2A) is shown in Fig.5.10. The circuit of this filter is shown in Fig.5.11 and its measured frequency response is shown in Fig.5.12. The rejection at 1MHz was measured at 40dB. Fig.5.13 shows the simple test circuit used. Finally, radiation from cables can be significantly reduced by fitting clamp-on ferrite cores (see Fig.5.14).

Clamp-on ferrite cores consist of two semi-circular cores that can be quickly and easily snapped onto cable in a single operation and without the need to cut the cable or remove any existing connectors. They are available in various grades and dimensions and are usually more effective when mounted close to the incoming supply connectors of EMI-producing equipment.

When selecting a clamp-on core for a particular application it is advisable to check manufacturers' data sheet specifications for their recommended frequency range and attenuation characteristic. It is also worth noting that the effectiveness of most cores increases with frequency (up to a maximum for the core in question) and attenuation can be significantly improved by winding several turns through the core. For example, a popular Fair-Rite clamp-on ferrite core exhibits an impedance of 200Ω at 50MHz with only a single pass-through conductor but this increases to 800Ω and 1.9kΩ with two and three turns respectively.

Going further

This section (shown above) details a variety of sources that will help you locate the component parts and further information that will allow you to understand EMC and improve the EMI and EMS performance of your electronic designs and equipment. It also provides links to relevant regulations and underpinning knowledge.

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SEPTEMBER 2021		
USB SuperCodec PCB	01106201	14.95
Audio DDS Oscillator PCB	01110201	5.95
Audio DDS Oscillator rotary encoder	01110201-ENC	6.95
Programming Adaptor Board for Audio DDS Oscillator	01110202	5.95
High-power Ultrasonic Cleaner main PCB	04105201	£14.95
High-power Ultrasonic Cleaner front-panel PCB	04105202	
Night Keeper Lighthouse PCB	08110201	5.95
AUGUST 2021		
Ol' Timer PCB	19104201	£11.95
Ol' Timer 8x8 RGB LED module using WS2812B	19104201-88	£8.95
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Ol' Timer DS3231 RTC IC wide SOIC-16	19104201-RTC	£5.95
Wideband Digital RF Power Meter	04106201	£9.75
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Cool Beans SMAD display	CB-AUG21	£11.95
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ATtiny816 Breakout / Dev Board with Capacitive Touch	24110181	£9.75
IR Remote Control Assistant (Jaycar version)	15005201	£8.95
IR Remote Control Assistant (Altronics version)	15005202	£8.95
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Nutube Guitar Effects Pedal	01102201	£12.95
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PCBs for most recent *PE*/*EPE* constructional projects are available. From the July 2013 issue onwards, PCBs with eight-digit codes have silk screen overlays and, where applicable, are double-sided, have plated-through holes, and solder mask. They are similar to photos in the project articles. Earlier PCBs are likely to be more basic and may not include silk screen overlay, be single-sided, lack plated-through holes and solder mask.

Always check price and availability in the latest issue or online. A large number of older boards are listed for ordering on our website.

In most cases we do not supply kits or components for our projects. For older projects it is important to check the availability of all components before purchasing PCBs.

Back issues of articles are available – see Back Issues page for details.

Double-sided | plated-through holes | solder mask

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SEPTEMBER 2018		
3-Way Active Crossover	01108171	£22.60
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Power Supply For Battery-Operated Valve Radios	18108171	£27.50
	18108172	
	18108173	
	18108174	

PROJECT	CODE	PRICE
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Touchscreen Appliance Energy Meter – Part 1	04116061	£17.75
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JUNE 2018		
High Performance 10-Octave Stereo Graphic Equaliser	01105171	£15.30
MAY 2018		
High Performance RF Prescaler	04112162	£10.45
Micromite BackPack V2	07104171	£8.45
Microbridge	24104171	£5.60
APRIL 2018		
Spring Reverberation Unit	01104171	£13.95
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DDS Sig Gen Lid	Blue	£7.05
DDS Sig Gen Lid	Clear	£8.05
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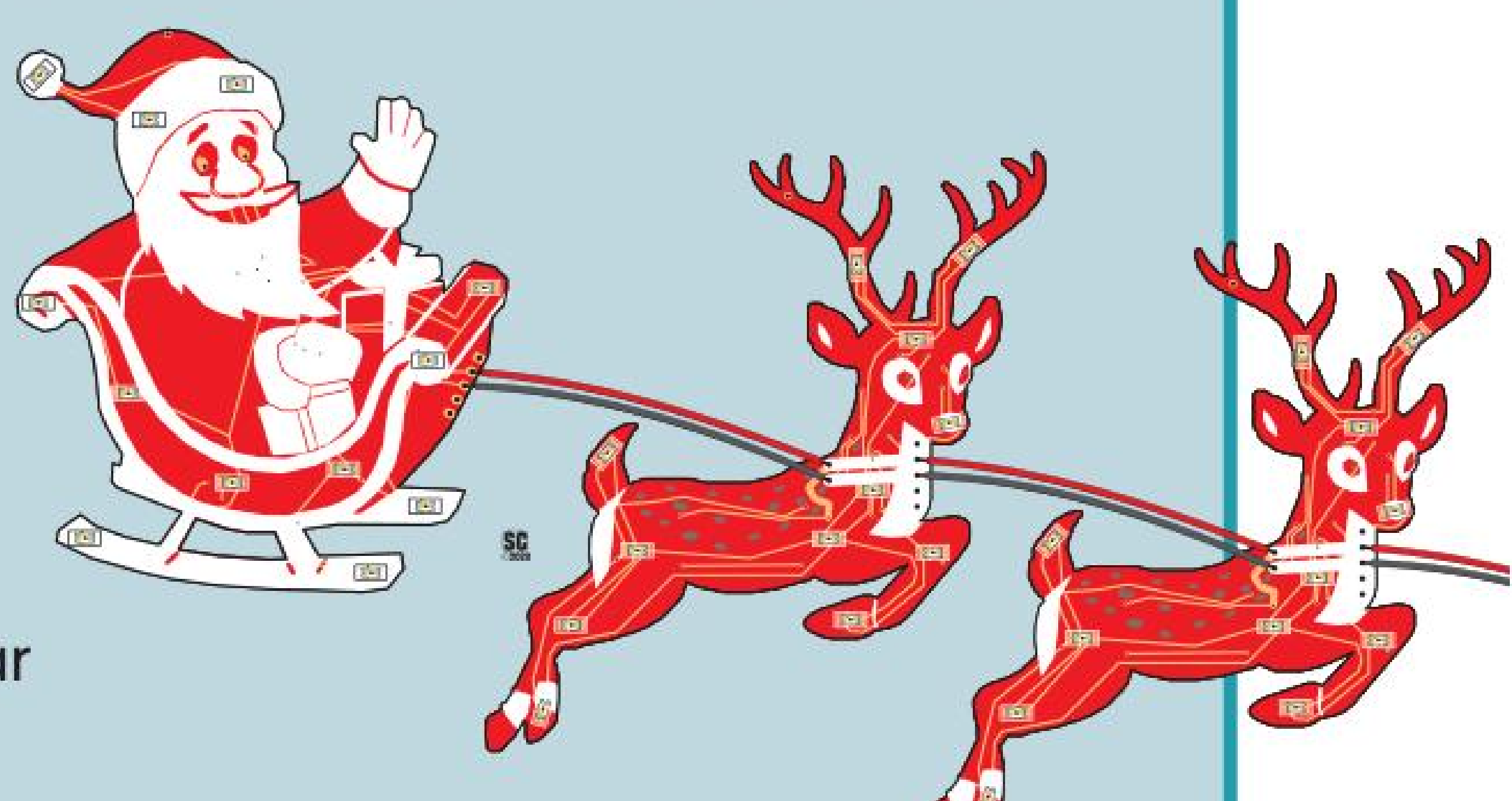
Next Month – in the November issue



Eight LED Christmas Decorations

Our *LED Christmas Tree* from last year was so popular we decided to follow it up in spectacular style with more festive decorations that you can build! They're small, cheap and easy to put together, so you could easily build all eight for Christmas this year; or even several of each.

Mini Digital Volt/Amp Panel Meters

There are many low-cost digital panel meters available which can display voltage and current at the same time. Quite a few have popped up on the market in the last year or so. So let's take a look at some of the more popular models, see what's inside them and whether they're easy to use.

USB SuperCodec – Part 3

Over the last two issues, we've introduced our new USB Sound Card, which we've dubbed the *SuperCodec*, and described its performance and operation in some detail. It offers extremely high recording and playback performance – so much so that our Audio Precision system can barely even measure its distortion! Now it's time to put it all together, and get it up and running.

Low-cost, high-precision Thermometer Calibrator

Many digital thermometers have readouts with a 0.1°C resolution but rarely are they accurate to within ±0.1°C. This simple, low-cost thermometer checker will tell you just how accurate your thermometer is. In some cases, you may even be able to adjust the thermometer to be more accurate.

PLUS!

All your favourite regular columns from *Audio Out, Cool Beans and Circuit Surgery*, to *PIC n' Mix* and *Net Work*.

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- **Continuous measurements.**
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- **Gold plated croc clips included.**
- **Can measure forward voltage of LEDs and LED strings too.**

atlas ZEN
model ZEN50
Vz=27.74V @ 15mA
Slope R=53Ω
Zener diode analyser
on - test
scroll - off

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Advanced firmware!

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- **Test frequencies: DC, 1kHz, 15kHz, 200kHz.**
- **Measure the true impedance of speakers and more.**
- **Great for hobbyists and professionals.**

LCR and impedance meter
Inductor 0.310%
L=701.1µH @15kHz
LCR45
on - menu
enter - off
Complex Impedance
Impedance 200kHz
+25.6 +j155.1Ω

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DCA55 Semiconductor Analyser - Identify your semi's

Now with backlit display and AAA battery!

Connect any way round to identify the type of component and the pinout! Also measures many parameters including transistor gain, base-emitter voltages, MOSFET thresholds, LED voltages etc. Complete with a comprehensive illustrated user guide. Includes an Alkaline battery so you're ready to go straight away.

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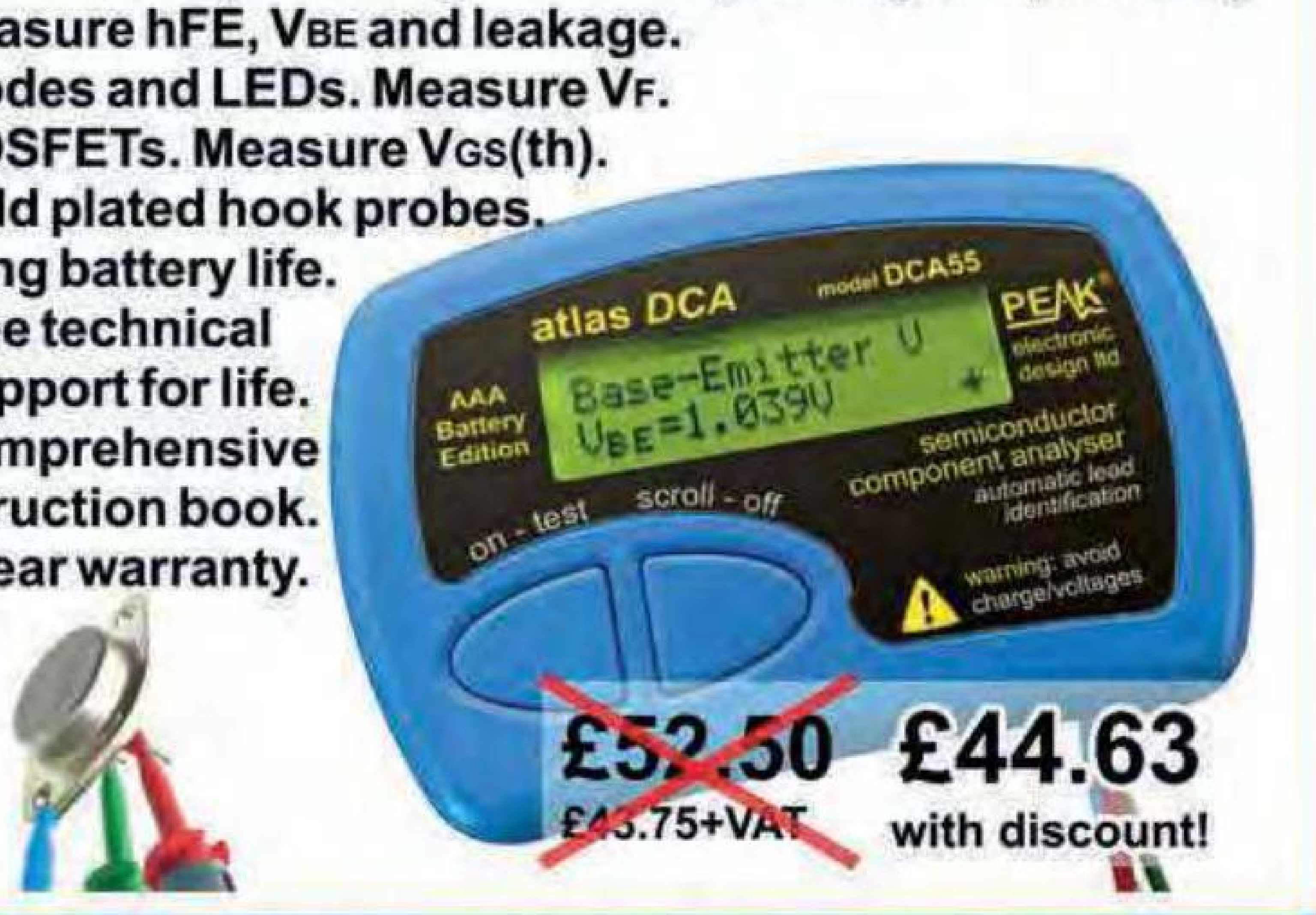
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ESR = 0.48Ω
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+ Audible Alerts
with automatic discharge function
on - test
off

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